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ENVIRONMENTAL PROTECTION AGENCY

Radiation Office

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INTERNATIONAL NUMERICAL MULTIPLE AND SUBMULTIPLE PREFIXES

Multiples and submultiples	Prefixes	Symbols	Pronunciations
10^{12}	tera	T	tĕr'a
10^{9}	giga	jĭ'ga	
10^{6}	mega	mĕg'a	
10^{3}	kilo	kĭl'o	
10^{2}	hecto	hĕk'to	
10	deka	dĕk'a	
10^{-1}	deci	dĕs'i	
10^{-2}	centi	sĕn'ti	
10^{-3}	milli	mĭl'i	
10^{-6}	micro	mi'kro	
10^{-9}	nano	năn'o	
10^{-12}	pico	pē'ko	
10^{-15}	femto	fĕm'to	
10^{-18}	atto	ăt'to	

SYMBOLS, UNITS, AND EQUIVALENTS

Symbol	Unit	Equivalent
Å	angstrom	10^{-10} meter
a	annum, year	
BeV	billion electron volts	GeV
Ci	curie	3.7×10^{10} dps
cm	centimeter(s)	0.394 inch
cpm	counts per minute	
dpm	disintegrations per minute	
dps	disintegrations per second	
eV	electron volt	1.6×10^{-12} ergs
g	gram(s)	
GeV	giga electron volts	1.6×10^{-3} ergs
kg	kilogram(s)	1,000 g = 2.205 lb.
km^2	square kilometer(s)	
kVp	kilovolt peak	
m^3	cubic meter(s)	
mA	milliampere(s)	
mCi/mi^2	millicuries per square mile	0.386 nCi/m^2 (mCi/km^2)
MeV	million (mega) electron volts	1.6×10^{-6} ergs
mg	milligram(s)	
mi^2	square mile(s)	
ml	milliliter(s)	
mm	millimeter(s)	
nCi/m^2	nanocuries per square meter	2.59 mCi/mi^2
pCi	picocurie(s)	10^{-12} curie = 2.22 dpm
R	roentgen	
rad	unit of absorbed radiation dose	100 ergs/g

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RADIOLOGICAL HEALTH DATA AND REPORTS

Volume 12, Number 4, April 1971

Radiological Health Data and Reports, a monthly publication of the Environmental Protection Agency, presents data and reports provided by Federal, State, and foreign governmental agencies, and other cooperating organizations. Pertinent original data and interpretive manuscripts are invited from investigators.

In August 1959, the President directed the Secretary of Health, Education, and Welfare to intensify Departmental activities in the field of radiological health. The Department was assigned responsibility within the Executive Branch for the collation, analysis, and interpretation of data on environmental radiation levels. This responsibility was delegated to the Bureau of Radiological Health, Public Health Service. Pursuant to the Reorganization Plan No. 3 of 1970, effective December 2, 1970, this responsibility was transferred to the Radiation Office of the Environmental Protection Agency which was established by this reorganization.

The Federal agencies listed below appoint their representatives to a Board of Editorial Advisors. Members of the Board advise on general publications policy; secure appropriate data and manuscripts from their agencies; and review those contents which relate to the special functions of their agencies.

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Department of Commerce
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ENVIRONMENTAL PROTECTION AGENCY

William D. Ruckelshaus, Administrator

Reports

Dose Assessment of Ionizing Radiation Exposure to the Population

Michael S. Terpilak, Charles L. Weaver, and *Samuel Wieder*[1]

The population dose from natural background, residual weapons test fallout, nuclear power operations, and medical and dental uses of ionizing radiation has been reviewed. Reported and projected population exposures from these sources indicate that, for the near future, the predominant exposure to the public will be attributable to natural background and to medical x rays. A continual evaluation to assess priorities, based on magnitude and type of exposure, and investigations into the biological effects of radiation constitute important features of public health responsibility.

A declining trend is in prospect for exposure to weapons test fallout in the absence of major atmospheric nuclear explosions. Exposure resulting from all procedures related to nuclear power operations and from diagnostic medical radiation (x rays and internally administered radionuclides) is projected to become of increasing importance. These warrant increased attention in planning for surveillance. Surveillance associated with peaceful uses of nuclear explosions (Plowshare Program) and with tests of nuclear engines for propulsion requires individual programming.

The assessment of total population exposure to ionizing radiation requires consideration of all sources of such exposure, natural and man-made. A substantial amount of information is available about the population dose from natural background, residual fallout from nuclear weapons tests, and medical and dental x rays. The population dose from operations of nuclear reactors, nuclear fuel reprocessing plants, and other sources of ionizing radiation is currently being studied and ranges of exposure are being estimated. Public health agencies will increasingly direct their activities to the evaluation of potential health effects of radioactive releases from the operations of an expanding nuclear industry, including the peaceful applications of nuclear explosions.

A staff study was made to evaluate the population exposure from the sources listed in table 1. This report presents the findings of this review and suggests some implications relative to the operational program of the Division of Surveillance and Inspection, Radiation Office. In this presentation, it is convenient to distinguish between exposure from natural sources, that from man-made sources excluding environmental contamination, and that from environmental contamination.

Table 1. Sources of irradiation

A. Irradiation from natural sources
1. Cosmic rays
2. Radiation from naturally occurring radioactive materials
B. Irradiation from man-made sources excluding environmental contamination
1. Medical irradiation due to:
a. Diagnostic x-ray procedures
b. Radiotherapy (external or from sealed sources)
c. Internally administered radioisotopes
2. Occupational irradiation
3. Irradiation from consumer devices
C. Irradiation from radioactive contamination of the environment due to:
1. Explosions of nuclear weapons
2. Operating nuclear facilities
3. Peaceful uses of nuclear explosives

Natural sources

Natural radiation exposure originates from interactions of primary cosmic rays with the earth's atmosphere and from the radioactive decay of naturally occurring radionuclides. These radionuclides contribute both an external and an internal exposure.

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Cosmic rays

Primary cosmic rays are of extraterrestrial origin and interact with the upper layers of the atmosphere, producing secondary rays (both electromagnetic and particulate radiation) to which all living beings are exposed (*1*). These secondary rays contribute about one-third of the natural external radiation at sea level. Higher contributions from both primary and secondary rays occur at very high altitudes (*2*).

The dose rate from cosmic rays at sea level is about 30 mrem/a and varies about 10 percent at sea level (*1–3*). The rate is, however, much higher in areas of high altitude. The exposure nearly doubles for each 1.5 kilometer increase in altitude up to about 7 kilometers. At altitudes above about 8 kilometers, the dose rate increases more rapidly. Populations living at 3 kilometers (10,000 feet) could receive a cosmic ray dose about four times that received by those living at sea level (*4*). Cosmic radiation measurements made in major cities in the United States showed ranges from less than 4 μR/h in coastal areas to nearly 9 μR/h in some cities in Colorado and Wyoming (*5*).

Terrestrial irradiations

The naturally occurring radionuclides which contribute significantly to the external irradiation of man are the uranium-238 and thorium-232 daughters. These nuclides are present practically everywhere, but their abundance varies widely from area to area. It is estimated that the average external exposure from terrestrial gamma rays to which the population is exposed, ranges from 25 to 75 mR/a.

In certain areas where the soil is particularly rich in radioactive ore, such as alluvial deposits of monazite, population exposure rates are much higher. In the Brazilian states of Espirito Santo and Rio de Janeiro, about fifty thousand people who dwell on deposits of this thorium-bearing mineral receive from 0.5 to 1.0 R/a. Elsewhere in Brazil, in the states of Minas Gerais and Goias, mineralized volcanic intrusives containing radioactive minerals are present. In one village of 350 people, these minerals produce exposures up to 12 R/a. In the areas of Kerala and Madras (India) where nearly one-hundred-thousand people live, the exposure to these inhabitants varies from 0.2 to 2.6 R/a (*4*). These appear to be the only densely populated areas where the irradiation from naturally occurring radionuclides is known to be so high. Some population groups are also exposed to higher than average radon-222 levels due to local climatic conditions (frequent inversions).

Total external natural exposure

Solon et al. (*5*) undertook an extensive series of measurements throughout the United States and found that the external environmental radiation exposure rates in populated areas ranged from 73 mrad/a in New Haven, Conn., to 197 mrad/a at Colorado Springs, Colo. Other studies on measurements of natural background gamma radiation showed average exposure rates ranging from 5.1 μrad/h near Facil, Fla., to 14.6 μrad/h in Fort Morgan, Colo. (*6*). These studies were made in areas away from man-made surfaces to avoid the effects of disturbed soil or building materials. In addition, an altitude correction was included in the calibration formula to adjust for the lower sensitivity of the instrument to high energy cosmic radiation, which increases at higher elevations.

Internal exposure

Air, drinking water, and food contain variable amounts of radioactive material of natural origin which may be deposited in the body after ingestion or inhalation. The main natural radioactivity of the body arises from elements of the uranium and thorium decay series and from potassium-40 and carbon-14. Internal dose rates from natural sources of radioactivity in "normal" areas of the world have been summarized by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (*2*) and are shown in table 2. It has not been possible to assess accurately the variability of dose rates received by different populations, but the major component, potassium-40, is a constant fraction of total potassium worldwide, giving doses that depend on body composition of muscle, fat, and bone.

Table 2. Dose rates due to internal irradiation from natural sources in "normal" areas

Source of irradiation	Dose rates (mrad/a)	
	Gonads	Bone marrow
Potassium-40	20	15
Rubidium-87	.3	<0.3
Carbon-14	.7	1.6
Radium-226	----------	.03
Radium-228	----------	.03
Polonium-210	.3	.3
Radon-222 (dissolved in tissues)	.3	.3
Total[a]	22	18

[a] Rounded to 2 significant figures.

Man-made sources excluding environmental contamination

Medical exposure

This category consists of those irradiations which are administered to patients by radiologists, general practitioners, dentists, etc., for diagnostic or therapeutic purposes. Radiological procedures in medicine are finding increasing use. At the same time, however, these procedures require continuing consideration of both medical benefits and radiation risks.

Diagnostic x-ray procedures

The 1964 X-Ray Exposure Study conducted by the Bureau of Radiological Health was designed to produce estimates of the magnitude of x-ray exposure to the U.S. population. The number of persons x-rayed, types of examinations, and exposure from these examinations were published in a report, "Population Dose from X-rays, U.S. 1964" (*7*). The genetically significant dose is defined as the gonad dose which, if received by every member of the population, would result in the same total genetic effect to the population. This definition is based upon the following assumptions and considerations:

1. The relevant tissue dose is the accumulated dose to the gonads;
2. The individual gonad dose is weighted with a factor which takes into account future number of children expected of the irradiated individual compared with an average member of the population (in this connection, the fetus is treated as such an irradiated individual and not as the child of an irradiated parent).

The genetically significant dose for the U.S. population (1964) was found to be 55 millirads per person per year. The genetically significant dose from dental procedures was well below 1 millirad (*7*).

External radiotherapy

In therapy, not only x rays but also beta and gamma rays are used, the latter provided either by application of sealed isotopes (for instance, radium or strontium-90 plaques) or by exposure to cobalt and cesium teletherapy units (*1*). The available estimates of the population average genetically significant doses from external radiotherapy for nonmalignant conditions in four European countries ranged from 2.2 to 4.5 mrem/a (*1*). These are much lower than the genetically significant doses due to diagnostic procedures. The frequency of therapeutic irradiations is, however, very much lower than the frequency of diagnostic irradiations, and the child expectancy of the therapy patients is often lower.

Since radiotherapy is used in the treatment of nonmalignant and malignant conditions, it is necessary to evaluate in any consideration of genetically significant dose, the effect of the disease itself and also of the irradiation on the relative child expectancy. It may be assumed that neither the nonmalignant conditions nor the radiation doses, with the possible exception of those in the regions of the gonads, affect the fertility of patients. However, for patients suffering from malignant conditions, the life expectancy is usually shorter than in the general population, and in each age group of such patients a less number of children will be conceived as compared to the statistics for the whole population (*1*). The UNSCEAR publication cites an estimate by Clark that the annual per capita dose to the total United States population from external radiotherapy is 12 mrem. He assumed that the gonad doses from irradiation for malignant conditions were of no genetic significance. In Austrialia, Martin estimated the annual genetically significant dose from external radiotherapy to be 28 mrem (*1*). These values were employed in the Federal Radiation Council

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(FRC) Report No. 1 and reported as average annual genetically significant doses to the population (*3*).

Thus, available estimates of genetically significant doses due to external radiotherapy range up 28 mrem/a; additional work is required to refine the dose estimates.

In recent reports (*8-9*), the use of brachytherapy and teletherapy procedures was surveyed. In 1966, it was estimated that about 50,000 patients received brachytherapy. It can be seen from table 3 that radium is the most widely used of the eight radionuclides listed, accounting for 58 percent of the total number of treatments.

The survey results for teletherapy procedures are summarized in table 4. The data show that 157,078 patients received a total of 1,919,948 teletherapy administrations, for an average of about 12 administrations per patient. The only condition reported as treated by teletherapy was cancer. Ninety-seven percent of the treatments used cobalt-60; the remainder used cesium-137.

Internally administered radioisotopes

Internally administered radioisotopes are used both for diagnostic and therapeutic purposes and are applied on an increasing scale because of their greater availability, improved techniques, and better understanding of physiology and biochemistry. The use of these materials, generally designated as radiopharmaceuticals, has not only increased but has also undergone changes with respect to choices of the radioactive element used or of the isotope of a given element. For example, between 1959 and 1966, the relative frequency of the use of iodine-131 declined, while the use of iodine-125 increased. Similarly, the use of radiopharmaceuticals labeled with cobalt-60 declined, while those labeled with cobalt-57 increased. Such substitutions are made for reasons of reduction of radiation dose and improved diagnostic effectiveness. Additionally, radioelements such as technetium-99m, selenium-75, and indium-113m have found increasing use in diagnosis, and the radioactive noble gases, xenon-133 and krypton-85, are

Table 3. Principal brachytherapy procedures reported by respondents to survey during 1966[a]

Radionuclide	Composition	Procedure	Physicians licensed for procedure	Physicians performing procedure	Patient administrations	
					Number	Percent
^{226}Ra	Sealed sources	Intracavitary Rx of cancer	734	543	15,700	31.6
^{90}Sr	Eye applicator	Ophthalmic treatment	483	295	11,785	23.7
^{226}Ra	Plaques and moulds	Dermatological treatment	378	109	5,582	11.2
^{226}Ra	Needles	Interstitial Rx of cancer	604	276	4,152	8.4
^{222}Rn	Seeds	Interstitial Rx of cancer	436	158	3,069	6.2
^{60}Co	Needles or seeds	Intracavitary Rx of cancer	283	90	2,737	5.5
^{226}Ra	Nasopharyngeal applicator	Intracavitary Rx of cancer	306	50	2,457	5.0
^{90}Sr	Plaques	Dermatological treatment	8	7	1,182	2.4
^{90}Sr	Nasopharyngeal applicator	Nonmalignant conditions	6	6	678	1.4
^{137}Cs	Sealed sources	Intracavitary Rx of cancer	22	16	548	1.1
^{60}Co	Needles, wire, and so forth	Interstitial Rx of cancer	258	31	547	1.1
^{192}Ir	Seeds—nylon ribbon	Interstitial Rx of cancer	51	32	404	.8
^{226}Ra	Nasopharyngeal applicator	Nonmalignant conditions	18	12	383	.8
^{198}Au	Seeds	Interstitial Rx of cancer	20	12	106	.2
^{226}Ra	Eye applicator	Ophthalmic treatment	7	6	100	.2
Total for principal procedures listed above					49,430	99.6
Total for 9 other procedures with less than 100 administrations					192	0.4
Total for all brachytherapy procedures					49,622	100.0

[a] Comprises responses from less than 50 percent of mailed questionaires.

Table 4. Principal teletherapy procedures reported by respondents to survey during 1966[a]

Radionuclide	Procedure	Physicians licensed for procedure	Physicians performing procedure	Patients	Patient administrations	
					Number	Percent
^{60}Co	Beam therapy	524	399	153,714	1,859,845	97
^{137}Cs	Beam therapy	76	25	3,364	60,103	3
Total for all teletherapy procedures				157,078	1,919,948	100

[a] Comprises responses from less than 50 percent of mailed questionaires.

used in studies on the circulatory system (*9*).

The number of admininstrations of radioisotopes for medical reasons in the United States has been variously estimated at 270,000 (*1*) and 400,000 (*9*) for 1959. By 1966, this rate had increased to about 1,500,000 (*9*) (see, however footnotes to tables 3 and 4), and a more recent estimate (*10*) indicated that by 1970 there were some 8,000,000 administrations of radioisotopes annually for treatment and diagnosis.

Calculations of dose, and particularly of genetically significant dose, from the use of internally administered radionuclides are difficult. A schema for such calculations for individual administrations has been published (*11*). Dose assessment depends on a large number of variables, including: the amount, purity, carrier, and chemical form of the radionuclide; distribution, metabolism, energy spectrum, and half-times of the radioactive material at the total-body, organ, and sub-organ levels; and the influence of the patient's age, body structure, and clinical status on the distribution and elimination of the radionuclide.

In a symposium on medical radionuclides, considerations of dosimetry and radiation effects were discussed for the various kinds of radionuclide administration (*12*). Principles and procedures for calculating absorbed dose were presented by a number of investigators (*13–16*).

The increased rate of administration of radiopharmaceuticals does not necessarily result in a corresponding increase in population dose. Improved instrumentation and procedures for function studies and tissue scanning and the availability of new tracer agents have materially lowered the patient dose in many procedures. Wellman, Kereiakes, and Branson (*17*) reported on the thyroid doses in children (in rads per microcurie administered) receiving iodine-131, iodine-125, and iodine-123 as sodium iodide. Between iodine-131 and pure iodine-123, the reduction in dose was nearly two orders of magnitude. The largest doses were received by the youngest children for each isotope. Similarly, McAfee (*18*) observed that the doses to the kidneys and the liver were reduced by about an order of magnitude when mercury-197 was used instead of mercury-203 as chloromedrin in equivalent microcurie quantities.

Whole body doses have been calculated (*17*) from administrations of chromium-51 (as sodium chromate) and of iron-59 (as ferrous citrate). Whole body and organ doses were also reported for other radiopharmaceuticals: mercury-197 (chloromedrin), mercury-197 and -203 (neohydrin), selenium-57 (selenomethionine), calcium-47 (calcium chloride), strontium-85 (strontium nitrate), technetium-99m (Tc-Fe complex, Tc sulfur colloid, and TcO_4). These studies were all done in children.

Mean dose rate to the whole body and to various tissues and organs were estimated by Cloutier and Watson (*19*) for phosphorus-32, chromium-51, iron-59, technetium-99m, and iodine-131. These investigators also provided data which distinguished between mean dose rates from nonpenetrating radiation and those from gamma radiation. This distinction has special relevance in nuclear medicine, particularly in the case of radionuclides that emit weak beta particles and exhibit "hot spots" at the cellular or subcellular level (*18–20*). Similar considerations apply to radionuclides that decay by electron capture (*18*) as in the case of iodine-125. Average doses to various hard and soft components of bone and to bone marrow have been calculated by Spiers (*21*) following admininstration of the beta-emitting radionuclides, carbon-14, calcium-45, sodium-22, fluorine-18, phosphorus-32, and strontium-yttrium-90.

Some comparisons have been made between doses from x rays and radioisotopes in various diagnostic procedures (*22*). It is to be expected that the dose distributional patterns will differ widely for the two types of procedure. The region of diagnostic interest will, of course, be the prime factor in determining the relative dose to tissues situated in the region. Thus, in examinations directed to the abdominal and pelvic areas, x radiation will deliver larger doses to the gonads than will most radiopharmaceutical procedures. The reverse is true of examinations involving the head and chest. In general, skeletal examinations with the use of bone-seeking radionuclides (fluorine-18, strontium-85) will result in higher bone doses than would be the case with x-ray examinations.

The genetically significant dose (GSD) to the population from radiopharmaceuticals is still very small compared to that from x-ray examinations. Trott et al. (*22*) estimated that in the United Kingdom diagnostic radioisotopes "probably still contribute less than 1 percent to the total genetic

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dose due to medical use of ionizing radiation." Early estimates (*1*), based principally on administrations of iodine-131 and phosphorus-32 before 1960, gave GSD values ranging from 0.01 to 0.03 mrem/a for diagnostic radioisotopes.

A recent study of a sample of hospital inpatients receiving in vivo radioisotope tests provided some comparisons of doses to the whole body, gonads, and various organs from diagnostic radionuclides and x rays (*23*). The authors found that in this sampling, the average gonad dose for these patients from radioisotopes increased from 0.06 rad in 1964 to 0.14 rad in 1968, while the average total body dose increased from 0.1 rad to 0.16 rad. The average gonadal exposure from x-ray examinations of these same individuals remained unchanged at about 1.2 rad. During this period, the total number of radioisotope procedures increased by 106 percent, while that for x-ray procedures increased by 48 percent. The gonad dose data obtained in this study should not be considered in terms of genetic effects since most of the patients were 45 years of age or older. It is of interest, however, that the study confirms other findings of an increasing trend in the use of radioisotopes and their potential contributions to population dose.

Occupational exposure

Individuals may be exposed to radiation as a consequence of their occupation, either because they are directly engaged in radiation work (medical practices, industry, research, etc.) or because their occupational activities take place where exposure to radioactivity is significant. The exposures can be external or internal, the latter arising through inhalation of radioactive gases and dusts and through the ingestion of radioactively contaminated material. Data available on the number of subjects occupationally exposed shows a maximum of 1.8 individuals per thousand of population. Other data available from UNSCEAR reports on the occupational genetically significant dose indicate that it does not exceed 0.5 mrem/a as averaged over the whole world (*1*). Doses to individuals of particular occupations, however, may range much higher. For example, the skeletal and gonadal doses from polonium-210 to uranium miners are as high as 6.6 rem/a and 150 mrem/a, respectively (*24*).

Exposure from consumer devices

Many objects in common use contain radioactive material or emit radiation. Luminous watch and clock dials are the most common, but a host of luminous devices is to be found on the market in increasing numbers. A number of other objects also incorporate radioactivity; these include static charge eliminators, smoke detectors, electronic tubes, and ceramic glazes containing uranium. X rays are emitted from television sets and from other electronic devices. The contributions to the genetically significant dose from each of these sources are small.

The use of these miscellaneous sources is likely to contribute about 2 mrem/a (*3*) mainly from the use of luminous clocks and watches, and television. However, with the increasing use of miscellaneous sources of radiation, none of which individually contributes an appreciable dose, the total genetically significant dose may be expected to increase slightly.

An estimate of exposure from man-made sources other than evironmental contamination was presented in a Federal Radiation Council report (*3*). The estimate was based on reports published before 1960 and probably would not hold for present conditions.

A more recent estimate of relative exposures was made by Morgan (*25*). He estimated that 94 percent of the total GSD from man-made sources of ionizing radiation was due to medical exposure, and 90 percent of this was from diagnostic x rays. Of the balance of 6 percent, 4 to 5 percent was attributed to weapons fallout and 1 to 2 percent to all other sources (occupational exposure, luminous watch dials, color television receivers, radioisotope applications, etc.).

Environmental contamination

Nuclear weapons fallout exposure

Debris from atmospheric nuclear tests remains the most important man-made radioactive contaminant of the environment. Many radionuclides of various half-lives are present in fallout. Those which have received the most attention are:

Radionuclide	Half-life
Zirconium-95	65 days

Niobium-95	35 days
Cesium-137	30 years
Strontium-90	28 years
Carbon-14	5,730 years
Iodine-131	8 days

Some of these contribute to both internal and external exposure; others to internal exposure only. The main contributions to external irradiation from fallout come from the first three abovementioned nuclides, all of which emit gamma rays. Because of the great difference between their half-lives, the respective contribution from stratospheric fallout from $^{95}Zr-Nb$ and ^{137}Cs to the total tissue dose depends on the stratospheric residence time. Because of the relatively short half-life of zirconium and niobium, much of their decay may occur before deposition whereas cesium-137, with a half-life of 30 years, decays mainly after deposition on the ground and consequently contributes a substantial tissue dose. Strontium-90, cesium-137, iodine-131, and carbon-14 are the main contributors to internal exposure. The amounts, the relative proportion of different nuclides, and subsequent exposures vary with time. Since fallout deposition shows wide geographical variations, estimating the dose received by the world population as a whole is particularly complex. The dose rate in a given year must be seen in context with all the separate and varying yearly dose rates from all radionuclides in order to obtain an estimate of the total dose. It is, therefore, more appropriate to compute the total integrated dose contribution that is being and will be delivered from past explosions. This contributon is called the dose commitment.

The dose commitment from nuclear tests carried out before 1968 has been estimated by the UNSCEAR (*26*). The dose commitments to the gonads from external radiation sources (short-lived radionuclides and cesium-137) ranged from 72 mrad in the north temperate zone to 16 mrad in the south temperate zone. The gonadal dose commitment from internal sources (cesium-137 and carbon-14) were 34 and 17 mrad, respectively, for the two zones. For dose commitments to the cells lining the bone surfaces, the contribution of strontium-90 (130 mrad in the north temperate zone and 28 in the south temperate zone) was added. In the case of dose commitments to the bone marrow, the respective contributions of strontium-90 were 64 and 14 mrad. The contribution of strontium-89 was less than 1 mrad in all cases.

In presenting these data, the UNSCEAR stated:

"Most of the amount of long-lived nuclides injected into the stratosphere by earlier tests had been deposited by the middle of 1967. However, substantial fractions of the total doses to which the population is committed remain to be received from present body burdens and from the deposit in soil which will continue to be transferred to foodstuffs. This is particularly true in the case of strontium-90 which remains available for absorption by plant roots and is retained for long periods in the human skeleton. Present estimates indicate that roughly one-eighth of the total expected population dose due to strontium-90 had been delivered by the end of 1967, compared with between two-thirds and three-quarters of that due to the total amount of cesium-137 available for deposition in the body. On the other hand, only a small fraction of the expected population dose due to carbon-14, the radioactive half-life of which is much longer, has so far been delivered, and somewhat less than one-tenth of it will have been delivered by the year 2000. By contrast, more than half of the contribution to the dose commitment from external sources has already been delivered.

For the purpose of estimating dose comments, UNSCEAR has used more extensively than heretofore actually measured levels of long-lived radionuclides in human tissues. This is particularly so in the case of strontium-90, which poses special problems because of its long retention in soil and bone and because of its complex metabolism in human tissues. By making use of measured levels in tissues, UNSCEAR has been able to avoid some of the assumptions previously needed. Though a large number of other assumptions are still necessary and are common to all methods of calculation, the method now used will enable UNSCEAR to use more efficiently the results of future measurements to verify and, if necessary, modify those assumptions in the future."

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Operating nuclear facilities

Based on data compiled by the Division of Environmental Radiation, Bureau of Radiological Health (now the Radiation Office, EPA), and presented in table 5, it appears that nuclear power stations with one exception were operating today at approximately 1 percent of their annual average noble gas discharge limits as provided in their technical specifications. Data from environmental samples obtained in the boiling water reactor study at the Dresden Nuclear Power Plant site show that radioactivity was not detectable in the water or food pathways; thus, measurable population exposure is restricted to external exposure from the noble gas plume where radiation was detectable. Exposures via this mechanism were very difficult to measure with certainty because gaseous releases from the plant resulted in environmental levels which were only a small fraction of background levels and therefore difficult to distinguish from background. Initial measurements of external dose rates showed that the offsite external dose rates vary from 5 to 15 mrem/a depending upon location, time, and technique of measurement. The offsite external dose rate of 5 to 15 mrem/a measured at the 200 MWe Dresden Nuclear Power Station can be used to obtain a conservative estimate of external exposures resulting from such power plants operating at higher power levels if the noble gas dose rate is assumed to be proportional to power level. This linear extrapolation of dose rate with power level is conservative because fuel performance will improve with advances in reactor technology, thus lowering the core fission product inventory escaping via leaking fuel elements. However, multiple plant siting may increase the external exposure rate in the multiple plant site environs and tend to make the linear extrapolation based on power level less conservative. The plume exposure from a pressurized water reactor would be expected to be much less due to its lower emission of noble gases.

Multiple reactor sites present problems relative to the establishment of radioactive effluent discharge limits in addition to those caused by the long-term buildup of radioactivity in the aquatic environment including the reconcentration phenomenon in biological media. These discharge limits will have to be developed carefully, utilizing the best available information and the many environmental aspects that influence the possible population exposure, to assure that the total dose to the population from multiple reactor sources is minimized. The potential impact of these exposures can be seen from table 6, which shows the populations within 10 miles and 50 miles of a number of nuclear power plants presently operating or under construction.

Peaceful uses of nuclear explosives

Potential population exposures from the peaceful applications of nuclear explosives—the Plowshare program—relate basically to three types of releases of radioactivity:

1. Releases from cratering shots,
2. Releases from ventings of underground shots,
3. Radioactivity in the flaring and, presumably, in

Table 5. Annual gaseous radioactive waste discharges expressed as percent of limit[a] (noble and activation gases)

Reactor	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968
PWRs[b]										
Shippingport	0.035	0.073	0.26	0.03	0.87	0.006	0.08	0.075	0.005	0.0025
Yankee			.000014	.32	.11	.014	.025	.035	.036	.008
Indian Point-1					4.5×10^{-7}	.00083	.0020	.0022	.0015	.0037
San Onofre									.0024	.00085
Connecticut Yankee									.00003	.0039
BWRs[b]										
Dresden-1			.158	1.29	.32	2.37	2.77	3.34	.87	1.09
Big Rock Point						.0025	.43	2.27	.85	.74
Humboldt Bay					.045	.38	12.5	17.8	56.7	54.0
HTGR[b]										
Peach Bottom-1								6.67×10^{-6}	.04	.087

[a] Table was taken from reference 27. This reference should be consulted for the quantities discharged and the discharge limits.
[b] PWR–pressurized water reactor; BWR–boiling-water reactor; and HTGR–high temperature gas-cooled reactor.

Table 6. Population density around nuclear power plants

Reactor	Location	Type[a]	Power level (MWt)[b]	Year operational	Year of population estimate	Population <10 miles	Population <50 miles
Browns Ferry Units 1, 2, & 3	Decatur Ala.	BWR	3,293	1972, 72, 73	1960	22,040	523,940
Calvert Cliffs Units 1 & 2	Lusby, Md.	PWR	2,450	1973, 74	1965	13,180	2,371,880
Connecticut Yankee	Haddam Neck, Conn.	PWR	1,473	1967	1960	49,640	[c]
Donald C. Cook Units 1 & 2	Bridgman, Mich.	PWR	3,250	1972, 73	1965	45,959	1,066,849
Diablo Canyon	Diablo Canyon, Calif.	PWR	3,250	1973, 74	1960	[d]1,570	151,490
						[e]3,500	
Dresden Unit 1	Morris, Ill.	BWR	700	1960, 70, 70	1950	21,000	[c]
Ft. Saint Vrain	Platteville, Colo.	HTGR	841.7	1972	1960	8,420	[c]
Indian Point Unit 1	Indian Point, N.Y.	PWR	615.0	1963	1960	155,420	[c]
Millstone Point Unit 1	Waterford, Conn.	BWR	2,010	1970	1965	[d]95,864	2,270,042
						[e]118,000	
Monticello	Monticello, Minn.	BWR	1,469	1970	1960	9,712	[c]
Oconee Units 1, 2, & 3	Seneca, S.C.	PWR	2,452	1971, 72, 73	1965	36,334	692,500
Oyster Creek Unit 1	Toms River, N.J.	BWR	1,600	1969	1960	37,456	[c]
Palisades	South Haven, Mich.	PWR	2,121	1970	1960	25,743	870,515
Prairie Island Units 1 & 2	Red Wing, Minn.	PWR	1,650	1972, 74	1960	15,292	[c]
Quad Cities Units 1 & 2	Cordova, Ill.	BWR	2,255	1971, 71	1966	39,488	[c]
Rancho Seco	Clay Station, Calif.	PWR	2,452	1972	1965	4,060	1,348,548
Russellville	Lowdon, Ark.	PWR	2,452	1973	1967	22,993	155,475
Sequoyah Units 1 & 2	Daisy, Tenn.	PWR	3,423	1974, 74	1960	24,920	604,120
					1980	54,325	757,545
Surry Units 1 & 2	Gravel Neck, Va.	PWR	2,441	1971, 71	1960	399,460	919,317
Turkey Point Units 3 & 4	Homestead, Fla.	PWR	2,097	1971, 72	1966	42,397	1,378,938
Zion Units 1 & 2	Zion, Ill.	PWR	3,391	1971, 73	1960	188,860	5,664,515
Average population <10 miles (permanent population using 1960 Sequoyah population)						59,991	
Average population <50 miles (using 1960 Sequoyah population)							1,386,000

[a] BWR–boiling water reactor; PWR–pressurized water reactor; HTGR–high temperature gas-cooled reactor.
[b] Refers to first reactor at site where more than one reactor exists or is being built.
[c] Not available.
[d] Permanent.
[e] Summer.

the ultimate distribution of natural gas from a cavity formed by a nuclear detonation. Such distribution has not taken place to date.

From December 1961 through September 1969, 24 Plowshare experiments were reported. Of these, six were primarily cratering experiments (one, a row charge cratering experiment with five simultaneous detonations), and two were gas stimulation experiments.

When releases from ventings and cratering shots occurred, the findings of radioactivity in milk were shown to be regional and spotty even within the regions affected (*28*, *29*). Monitoring of such releases is rendered difficult when it is considered that "calculations also indicate that milk levels of 1,000 to 5,000 [pCi iodine-131 per] liter could occur when external gamma levels due to fallout are too low to distinguish from natural background by routine field survey methods" (*30*). In view of the localized, sporadic nature of these exposures, it is inappropriate to attempt to calculate organ and genetically significant doses to the U.S. population from such occurrences.

Special considerations of environmental radionuclides

A number of potential sources of exposure requring special investigation, both from a dose commitment and biological effects standpoint, are: tritium, krypton-85, discharges of various other noble gases from nuclear facilities, doses resulting from occupancy of dwellings constructed on tailings from uranium mill operations, and doses to local population groups from intake of highly contaminated foods or water.

Tritium[2]

Tritium occurs naturally in the environment as a product of cosmic-ray bombardment of nitrogen in the upper atmosphere (*31*). It is also produced as a ternary fission product, as a product of thermonuclear reactions, by various types of reactions in nuclear reactors and in tritium production facili-

[2] We are indebted to the report of D. G. Jacobs, of Oak Ridge National Laboratory (*43*) for much of the material in this section.

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ties. Of chief concern from the standpoint of population exposure are the releases from past thermonuclear atmospheric tests and from operations of the nuclear power industry, particularly in the processing of nuclear fuels.

An early report on the tritium content of natural surface waters indicated that there was about one tritium atom for every 10^{18} atoms of hydrogen (*32*). Kaufman and Libby (*33*) estimated an inventory of about 1,800 g (17 megacuries) on the earth, with 11 g (0.1 megacuries) in the atmosphere, 13 g (0.12 megacuries) in groundwater, and the remainder in the sea. These estimates of natural tritium production and inventory may have been low, (*cf.* "Population doses and projections," below).

Contributions from nuclear explosions

Thermonuclear detonations are the principal considerations in this regard. Leipunsky (*34*) estimated that the explosion of a 10-megaton-equivalent pure hydrogen bomb (deuterium-tritium reaction) would result in a residue of 7 kg of tritium (about 66 megacuries). In addition to this direct yield from fusion reaction, the neutron irradiation of nitrogen may yield an additional 1.5 kg of tritium (*35*). (The neutron release from an equivalent fission explosion would yield about 0.2 kg of tritium.) In addition, interactions of neutrons with the materials of the device itself could lead to increased tritium releases ranging as high as 5 kg of tritium per megaton equivalent from the explosion of a fusion device (*36*).

The partition of tritium in the environment from fusion detonations will vary with the placement of the shot. A fraction of the fission-produced tritium migrates through the fuel cladding and reaches the primary coolant. In pressurized water reactors soluble boron and lithium are present in the primary coolant to regulate neutron flux. Neutron bombardment of isotopes, lithium-6 and boron-10, produces tritium. By 1960, the concentration of tritium in stratospheric water had risen by about five orders of magnitude over pretest levels.

Tritium releases from nuclear reactors

In light-water reactors, tritium is produced in the course of fission of the reactor fuel and by neutron bombardment of certain elements. Some tritium is produced by fast neutrons acting on boron-10 in the control rods, or in borate solutions used in some control systems, or on nitrogen-14 present in the residual air. Most of the tritium is produced by thermal neutron irradiation of deuterium, helium-3, or lithium-6 in the reactor coolant. The rates of release into the environment depend on the type and the operating conditions of the reactor and are normally low. Much of the fission-product tritium is retained within the cladding of the fuel elements and in the primary coolant system.

In heavy-water reactors, where the heavy water can be used as a moderator, reflector, and a coolant, tritium is formed primarily by neturon bombardment of deuterium and relatively little is lost from the heavy-water system. Some estimates of tritium releases from heavy-water reactors have been published. At Chalk River in Canada, some 3 curies of tritiated water vapor have been released daily from the stack (*37*). Releases to surface waters at the Savannah River Plant, primarily from the heavy-water reactors, have resulted in concentrations of tritium in the river ranging around 10 nCi/liter, which is less than 1 percent of the maximum permissible concentration (*38*). It has been suggested that tritium activity resulting from the operation of a large heavy-water power plant will be as important to radiological health as all other radionuclides combined because of its vapor pressure (*39*).

Tritium releases from fuel-reprocessing plants

Spent fuel from nuclear reactors is processed commercially at only one location in the United States at present. This facility, Nuclear Fuel Services, Inc. (NFS), is located in Cattaraugus County, N.Y. In the preoperational statement (*40*), it was estimated that about 200 curies of tritium would be released per day during reprocessing operations. Of this, 25 percent would be released through the stack, 65 percent via discharge into a waterway (Buttermilk Creek), and the remaining 10 percent would be held as waste storage. These estimated proportions are not too different from values reported for the Hanford Plant (*41*).

Monitoring of the atmosphere, liquid waste discharges and water in the NFS operational area showed the following: (a) the concentration of offsite tritiated moisture in the atmosphere tended to be highest northwest of the plant (*42*), reaching levels as high as 14 nCi/liter of atmospheric water; (b) the general practice of releasing liquid wastes in proportion to the flow in Cattaraugus Creek (which receives the flow from Buttermilk Creek) provided a degree of dilution such that the concentration averaged little more than 10 times the average concentration in the statewide surface water systems (*43*). Releases from fuel reprocessing plants result in relatively high local concentrations of tritium (and krypton-85, which will be discussed below). As the nuclear power industry expands and the number of fuel reprocessing plants increases, tritium is expected to become a substantial factor in consideration of population exposure.

Population doses and projections

Projections of fission-product tritium from nuclear power plants in the free world have been made for the period 1965 to 2000 (*44*). Based on predictions of power production, assumptions of load factors and thermal efficiency, and data derived from light-water-cooled reactor operations, it was estimated that by the year 2000 a total of 96 megacuries of tritium will have accumulated. If the production rate predicted for the year 2000 (15 megacuries per year) is maintained thereafter, a steady-state level of 260 megacuries of accumulated tritium will result.

Jacobs made an interesting observation on the probable value of natural tritium production, which was taken to range from 0.5 to 1.0 atom/cm^2-sec. This value would yield an annual production of about 4 to 8 megacuries and result in a steady-state inventory of 70 to 140 megacuries. In his projection of fission-product tritium produced in reactors, the rate of tritium produced would begin to exceed that of natural tritium about a decade before the turn of the century (*44*).

In a power economy in which heavy-water-moderated reactors assume a substantial role, or if thermonuclear reactors come into the picture, the rate of tritium production will be enhanced.

Local exposure to tritium can amount to an appreciable fraction of the Radiation Protection Guides. It has been calculated that in the reprocessing of fuel for 100,000 MW (thermal) production, the rate of release of tritium would be 14 mCi/s, and the atmospheric concentration at the plant site would be about 6 nCi/m^3. Assuming the stack release to be in the form of HTO, the average annual occupational dose to the whole body, through inhalation and skin absorption, would be 4 mrem/a. This was calculated on the basis of a 40-hour exposure per week, using a quality factor of 1.7. Under these conditions, a steady-state, ground-level air concentration of 1.1 nCi/m^3 would be reached about 1 mile away. The dose rate to the population in this area for constant (168-hour week) exposure would be somewhere between 2 and 3 mrem/a (*44*).

Additionally, the tritium sampling network of the Public Health Service has shown tritium values of 2 to 20 nCi/liter in surface waters of the United States (*45*, *46*). Assuming the same specific activity in the body, the estimated whole body doses in these areas would range from 0.33 to 3.3 mrem/a.

Dilution of the tritium, particularly that released to the atmosphere, will dissipate the exposure to the general population. Estimates of dose to the world population from tritium released in the course of projected United States nuclear power production in the year 2000 have ranged as low as 2 μrem/a (*47*).

Krypton-85 and other radioactive noble gases

Radioactive noble gases are fission products and are produced in the nuclear fuel system of reactors. Estimates of the yield of noble gas fission products from uranium-235 are presented in table 7 (*48*). In addition, certain types of reactors also produce radioargon, an activation product. For example,

Table 7. Noble gas fission products from uranium-235 (having yield >0.01 percent and half-life >1 min)

Isotope	Half-life	Yield (percent)
Krypton-83m	114 minutes	0.54
Krypton-85m	4.4 hours	1.10
Krypton-85	10.7 years	.29
Krypton-87	76 minutes	2.49
Krypton-88	2.8 hours	3.57
Krypton-89	3.2 minutes	4.59
Xenon-131m	12 days	.02
Xenon-133m	2.3 days	.17
Xenon-133	5.3 days	6.62
Xenon-135m	15.3 minutes	1.83
Xenon-135	9.1 hours	6.30
Xenon-137	3.9 minutes	6.00
Xenon-138	17 minutes	5.49

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the Brookhaven Graphite Research Reactor discharged over 20 kCi/day of argon-41 (110-minute half-life) while operating at 20MWt(*49*). During 1964, radiation levels at offsite monitoring stations averaged 0.06 mR/week from this source.

It is noteworthy that only one of the noble gas fission products, krypton-85, has a half-life measurable in years. It, therefore, presents the greatest potential for buildup in the environment.

An environmental surveillance study at a boiling water reactor (Dresden Nuclear Power Station of the Commonwealth Edison Company) has been reported in detail (*50*). This plant had been operating at a rated power of 700 MW (thermal) and 210 MW (electric) since 1962. The prominent noble gas radionuclides in stack effluent, as measured by gamma spectral analysis of delay-line samples, were krypton-85m,-87, and-88, and xenon-133,-135, and-138. Xenon-135 was the only radioactive noble gas among the major predicted constituents that could not be quantified. One day after release, only krypton-88 and xenons 133m, 133, and 135 were detected by gamma-ray spectrometry. After one month, only xenon-133 and krypton-85 were identified.

It is important to note that krypton-85 is predominantly a beta particle emitter. Its decay yields 99.565 percent of 0.675 MeV (maximum energy) beta radiation and 0.435 percent low energy beta radiation and gamma radiation of 0.514 MeV. The gamma photons occur in only 0.41 percent of the krypton-85 disintegrations. These characteristics in addition to the chemical inertness and low solubility of the gas, form the bases for determining doses to exposed populations.

Most of the krypton-85 produced in nuclear power reactors is released during the reprocessing of spent fuel. At any given time, the inventory of krypton-85 resulting from nuclear power plant operations will consist of: (a) the krypton-85 retained in the fuel elements, (b) that released from the reactor stacks, and (c) that stored in or released from the fuel reprocessing operations. The proportions will vary according to the type of reactor and the fuel exposure in the reactor.

Estimates of projected krypton-85 production have been prepared by a number of analysts (*51–53*). Their findings are shown in table 8.

Table 8. Cumulative krypton-85 production estimates

Source	Quantity (megacuries)				
	1970	1980	1990	2000	2060
Cowser et al. (free world) (*51*)	13	210	1,100	3,150	
Coleman and Liberace (world) (*52*)[a]	15.4	200	1,000	4,000	120,000
Mountain et al. (U.S. only) (*53*)	11	220	970	3,100	

[a] Assumes a changing mixture of reactor types, including thermal converters and fast breeders. Values calculated from concentration projections.

The premises and assumptions for the different calculations vary among the three projections, but the projections do not differ by anything like an order of magnitude.

Dose estimates based on the above projections, compiled by Fowler and Voit (*54*), are shown in table 9.

Table 9. Comparison of the estimated annual average skin surface dose from krypton-85

Source	Estimated annual average skin surface dose (mrem/a)				
	1970	1980	1990	2000	2060
Reference (*51*) (worldwide)	0.008	0.12	0.63	1.8	
Reference (*52*) (world)	.006	.08	.41	1.6	50
Reference (*53*) (U.S. only)[a]	.07	1.4	6.3	20	

[a] Basis used was dilution only over the tropospheric volume of the United States (2.69×10^{23} cm^3).

These estimated annual dose calculations relative to the beta radiation are applicable to the skin surface of the body. Attenuation of this beta radiation by the skin tissue occurs at a rate that yields a negligible whole body dose. Calculations by Fowler and Voit (*54*) and by Hendrickson (55), which show reasonable agreement, indicate dose rates at various tissue depths as listed in table 10.

Table 10. Calculated dose rates at various tissue depths

Depth in tissue (mm)	Percent of dose[a]
0 (surface)	100
.07 (shallowest layer of live skin)	52
.1	40
.2	20
.3	10
1.0	.08
2.0	.00008

[a] From krypton-85 beta radiation (maximum energy, 0.675 MeV).

Hendrickson (*55*) has also presented calculations of tissue doses from combined beta and gamma plus x radiation (bremsstrahlung). The total average energy of these penetrating rays was calculated to be 2.83 keV/disintegration (2.23 keV β-γ plus 0.6 keV bremsstrahlung). Based on a krypton-85 concentration in air that would produce a dose of 50 mrem/a to the skin surface (Coleman and Liberace projections for the year 2060) (*52*), the doses to tissues would be as shown in table 11.

Table 11. Tissue doses from immersion in air containing krypton-85 concentration of 20 pCi/g of air[a]

Tissue	Tissue depth (mm)	Beta radiation (mrem/a)	X and gamma radiation (mrem/a)
Whole body	[b]50	nil	0.7
Gonads	10	nil	.7
Gonads	2	4×10^{-5}	.7
Skin surface	0	50	.7
Skin[c]	.07	30	.7
Lens of eye	2	4×10^{-5}	.7
Lung[d]	0	0.5	.7

[a] Adapted from Hendrickson (*55*).
[b] Average.
[c] Shallowest layer of live skin.
[d] Internal exposure to surface tissue of lung.

Calculations of dose from krypton-85 dissolved in body fluids and tissues are in progress and will be published in the near future.

Thus, krypton-85 remains as a potential future source of environmental contamination requiring evaluation by those concerned with the balancing of risks and benefits of nuclear energy.

Various methods for removal of krypton-85 have been proposed. These have been reviewed by Fowler and Voit (*54*) and include solid absorption, cryogenic distillation, electrostatic diffusion, and permselective membrane separation coupled with underground storage of the separated krypton-85.

Other sources of exposure

To provide a basis for protecting the health of the public from undue exposure to ionizing radiation, it is necessary to establish a system which will provide a continuing evaluation of population exposure. This system must be responsive to all sources of radiation exposure and provide the technological data upon which decisions can be made with respect to the relative impact of each source in relation to the total exposure. Potential sources of exposure requiring critical investigation include, in addition to the factors discussed above:

1. Dose associated with peaceful uses of nuclear explosives (Plowshare Program);

2. Dose resulting from residence in an area with an unusually high radiation background; and

3. Doses to population groups that have special dietary intakes or other special exposure situations.

Limited amounts of data are available with respect to the production of radioactivity as a result of Plowshare experiments. Environmental survey findings have been reported following a cratering experiment (Project Schooner, a 35-kiloton fission explosion at the Nevada Test Site on December 8, 1968) (*56*). Gross beta radioactivity increased in a number of northwestern States, and fresh fission products were detected over a wide range of States. Only one Pasteurized Milk Network (PMN) station reported a detectable concentration of iodine-131, and two reported barium-140. The concentrations were close to their minimum detectable levels, and it was concluded that these did not represent a public health hazard.

Project Gasbuggy, a contained, natural gas-stimulation experiment, was conducted on December 10, 1967. Offsite surveillance revealed no radioactivity above preshot levels in air, milk, and water, and no intrusion of radionuclides into producing water wells in the vicinity (*57*). The gas produced has not been released into distribution pipelines and therefore presents no population hazard except possibly for the minimal exposure resulting from flaring of the gas.

A Federal program of monitoring dwellings constructed on uranium mill tailings was instituted during late 1970. Findings were not available as of the date of preparation of this report.

Dose estimates for populations with special dietary intakes will become increasingly important as nuclear installations proliferate. Honstead (*58*) has described studies indicating that radionuclide burdens in children in the vicinity of the Hanford Project were increased where diet sources were

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related to the Columbia River. The survey procedure described would provide dose estimates "to a typical resident and to a special population group having diet habits that maximize exposure."

Dose commitment concept

This refers to the procedure of attributing to a particular environmental contamination all the subsequent exposure that will result from the contamination. It was defined by the UNSCEAR (*2*) as follows: "... the dose commitment to a given tissue is ... the integral over infinite time of the average dose rates delivered to the world's population as a result of a specific practice; e.g., a given series of nuclear explosions. The actual exposures may occur over many years after the explosions have taken place and may be received by individuals not yet born at the time of the explosions..."

Utilizing this procedure, we can then consider such things as the dose commitment from all nuclear weapons testing prior to 1968. This implies that these nuclear weapons have contaminated the environment in an irreversible manner which has committed the population to this dose. Although the UNSCEAR definition relates to an infinite time integral, it should be realized that the per individual addition of dose is considered only for a life-time period (50 to 70 years).

This concept is useful in assessing the health impact of any given quantity of radionuclides introduced as the result of contaminating events. It could apply to a single intake episode (e.g., a dose of a thorium compound or other diagnostic radiopharmaceutical) or to describe natural radiation exposure, considering each person's exposure to start at the time of conception. Although the dose commitment concept has mainly been applied to the case of exposure of the world population to radiation from nuclear tests, the concept is, in principle, applicable to other cases. For estimating the value of the dose commitment, however, it may be necessary to take into account various specific properties affecting the distribution of dose among members of the population. The dose commitment is then obtained as the average of the dose commitments to the relevant subpopulations, appropriately weighted by subpopulation size.

Calculating the dose commitment then becomes mainly a problem of predicting changes in the amounts and distribution in the body of the relevant radionuclides. In practice, this may involve not only considerations of the metabolism of the nuclides in various organs and tissues, but also considerations of environmental vectors that contribute to both internal and external radiation dose.

The internal radiation dose commitment to the whole body or to a specific organ or tissue of an individual in a population group is the product of (1) the factor for converting activity intake of the specific radionuclide to dose, (2) the weight or volume intake of the media containing the radionuclide per individual per unit time, and (3) the concentration of the radionuclide in the media.

A summary of dose commitments to the gonads, cells lining bone surfaces, and bone marrow as result of nuclear explosions was presented in an UNSCEAR report (*2*). The period covered was 1954 to 1965, and the dose commitments listed dealt with external, short-lived radiation, carbon-14, cesium-137, and strontium-89 and -90. An evaluation of internal radiation exposure, based on dose commitments from radionuclides in milk, food, and air was performed by Shleien (*59*), using data from existing surveillance networks. This report provided dose commitments to critical organs (in mrem for 50 years) (1) for maximum doses to infants accrued in any one year, and for (2) adults from intakes occurring during various periods from 1961 to 1968 in the northeastern United States. The largest dose commitments in the adult group were the dose to bone from strontium-90 dietary intake and the dose to the respiratory lymph nodes from plutonium-239 and plutonium-238 inhalation during the 1965–1968 period. The plutonium resulted from two principal sources; atmospheric inventory from nuclear weapons testing, and the re-entry and burnup of an orbiting device carrying 17,000 curies of plutonium-238 in April 1964.

These dosimetric calculations provide information required for evaluation of present surveillance operations and guidance for future surveillance requirements. The procedure is potentially applicable to monitoring surveys around nuclear facilities and evaluation of possible releases from peaceful uses of nuclear energy (*59*). In some of these cases, the concept should be even eas-

ier to apply as there would be no need to consider injection and long-term holdup in the upper atmosphere as well as the fact that the population at risk would be more limited and better defined.

In view of widespread concern with the potential hazards of ionizing radiation in the environment, there is need for continuing review and evaluation of relevant information in order to reassess existing radiation protection standards. The evaluation should provide estimates of risks associated with low-level environmental radiation as a basis for reviewing the adequacy of current guidelines as applied to projected radiation levels. Based on projected exposures, the need for possible dose apportionment among the more important sources of radiation exposure should be considered. The International Commission on Radiological Protection (*60*) propounded a principle relevant to the subject in the following statement:

> "The suggested maximum genetic dose of 5 rems in addition to the dose from medical procedures and natural background must not be used up by one single type of exposure."

It is of interest, therefore, to examine in perspective those sources of exposure that present important areas of current and future public health concern.

Dose rates and dose commitments from natural background radiation remain constant worldwide. Surveillance of various geographic regions may have some value for purposes of studies of biological effects and for site selection for nuclear power operations. Assuming that there will be no substantial resumption of atmospheric nuclear detonations, the trend of dose commitment to the population from atmospheric fallout will decline. Table 12 compares the 50-year dose commitments from fallout produced by weapons tests conducted before 1968 with that from average natural background.

In addition, consideration should be given to other specific areas of dose commitment, such as: radioiodine dosage to the thyroid gland; radiostrontium, radium, radiobarium, and plutonium dosage to mineral bone; radioiron to blood-forming cells and spleen; and of various radionuclides to such tissues and organs of reference as the gastrointestinal tract, liver, lung, kidney, pancreas, and muscle. Guidance on the relative significance of exposure to specific radionuclides may be obtained by reference to National Bureau of Standards Handbook 69 (*61*).

Table 12. Fifty-year dose commitment (mrem) from fallout (weapons tests before 1968)[a]

Source	Whole body	Gonads	Cells lining bone surfaces	Bone marrow
Internal radiation from fallout:				
Cesium-137	21	21	21	21
Carbon-14	13	13	16	13
Strontium-90	.....	.....	130	64
Strontium-89	.....	.....	<1	<1
External (total) radiation from fallout:	50–100			
Short-lived	.....	36	36	36
Cesium-137	.....	36	36	36
Natural background radiation:				
External	4,000	4,000	4,000	4,000
Internal	1,050	950	1,200	1,000

[a] Adapted from reference (*3*).

A special case is the calculation of a genetically significant dose which, particularly for medical and occupational exposure includes in the "genetic pool" individuals not directly exposed in the particular procedure.

Trends toward increasing population dose commitments are attributable to two main areas of application of ionizing radiation: medical diagnostic x radiation and uses of radioisotopes, and the growth of nuclear power operations.

Medical (includes dental) uses of radiation for diagnosis

X rays

The population dose from x rays in the United States for 1964 has been evaluated in terms of estimates of gonad and genetically significant dose to the population (*7*). As indicated earlier, this genetic dose was estimated to be 55 millirads per person per year, 96 percent of which was contributed by radiography, about 4 percent from fluoroscopy, and a minute amount from photofluorography. Based on various assumptions with respect to increased rates of x-ray examinations and limited projected improvements in practice, Kessner and Brown (*62*) projected genetically

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significant doses ranging from 150 to 365 millirads per year to the population by 1990.

Administration of radionuclides

Dose calculations for systemic radionuclide administrations require a comprehensive assessment of dose to the whole body as well as to various organs of interest. Of particular interest for determining population (e.g., genetically significant) dose is the dose to the gonads. This is usually assumed to be approximately equal to the mean whole body dose (*22*). It has been estimated that for the near future, the annual growth rate of nuclear medicine would be as high as 15 percent (*63*). If we assume the genetically significant dose from nuclear medicine procedures to be about 0.5 millirads for the year 1970, a likely assumption if we accept the estimate of Trott (*22*), then the projected GSD for 1980 would exceed 2 millirads. To this should be added the doses to personnel engaged in the preparation, administration, and other handling procedures involved.

Nuclear power generating sources and associated operations

The population dose relatable to nuclear power operations would include the total exposure from mining and milling operations, transportation, processing, reactor applications, fuel reprocessing, waste storage and disposal, and are affected by dilution factors from releases into the environment as well as concentration factors in media that enter the food chain.

Radiation doses from all sources to which large or substantial portions of populations are exposed are regularly reviewed by advisory groups. In 1962, the National Advisory Committee on Radiation identified a number of public health problems concerned with radioactive contamination of the environment. It reaffirmed the responsibility of health agencies to maintain appropriate surveillance networks to provide continuing information of levels of environmental contamination affecting the public. It also emphasized the need to undertake broad research programs to develop countermeasures for the control of environmental contamination.

Morgan (*64*) has suggested for consideration a possible allocation of permissible genetic and/or body exposure of the population from man-made sources of ionizing radiation. An adaptation of his tabulation is shown in table 13. Column three of the table presents doses that he believes can be attained by the application of proper technology and practices. These are long range projections; some of the values are larger and others, smaller than present estimates of population doses from the source.

Table 13. Suggested levels of permissible genetic and/or whole body exposure of the population

Source	Radiation levels (mrem/a)	
	"Permissible"	"Attainable"
Nuclear power operations:		
Internal dose	50	5
External dose	17	2
Other industrial operations:		
Internal dose	30	3
External dose	15	2
Medical exposure { diagnostic	50 } 40	10 } 5
Medical exposure { therapeutic	50 } 10	10 } 5
Other occupational contributions to population dose	4	.1
Weapons fallout	2	
Miscellaneous (watches, television, high voltage switches, etc.)	2	.1
Total	~170	22

Additional exposures to individuals would include such things as 2 to 4 mrem for a commercial round-trip flight across the United States (*5*). Some doses to local populations may result from Plowshare operations or from nuclear rocket tests.

Discussion

A coordinated approach to the documentation and assessment of population exposure to environmental radiation from all sources is essential to the development of guidelines and countermeasures useful in minimizing hazards to public health. Federal agencies and most States have surveillance programs of varying degrees of adequacy. A continual evaluation to assess priorities based on magnitude and type of exposure and a program designed to improve our knowledge of the biological consequences of radiation constitute important features of the total public health responsibility. The information resulting from these programs, when made available in a responsible manner and on a timely basis, will provide the

groundwork for scientific and public perspectives on the needs and consequences (the so-called "benefit-risk" calculations) relative to the applications of radiation.

At the present time and for the foreseeable future, the predominant exposure to the public is attributable to natural background and to medical x rays. Exposure to residual fallout radioactivity presents a declining hazard. Exposure to nuclear power operations and especially to medical radiation (x rays and internally administered radionuclides) is projected to become of increasing consequence and therefore warrants increased attention in planning for surveillance. In addition, surveillance associated with peaceful uses of nuclear engines should form a part of future programs.

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Public Health Aspects of Iodine-129 from the Nuclear Power Industry

John L. Russell and *Paul B. Hahn*[1]

The production of iodine-129 in nuclear power reactors and its subsequent environmental releases during fuel reprocessing represent a potential long-term public health problem. Because of its extremely long half-life, any discharged iodine-129 is essentially a permanent contaminant in the biosphere, where it will eventually be found as a fraction of total iodine within a locality and possibly worldwide. This potential problem, its possible geographical scope, and the projected impact on population exposure are discussed along with data from measurements at nuclear power reactors and a fuel reprocessing plant.

A concentration of 0.86 percent iodine-129 in total iodine produces the dose limit recommended by the Federal Radiation Council (FRC) for a suitable sample of an exposed population. The quantity of iodine-129 discharged from operating power reactors was estimated from measurements of iodine-131 discharges by calculating an iodine-129 to iodine-131 buildup ratio. This analysis showed that the iodine-129 discharge from operating power reactors was negligible. Measurements at a fuel reprocessing plant indicated that approximately 10 percent of the total iodine-129 inventory in spent fuel was discharged from the stack during the batch dissolution process. The liquid discharge concentrations were about 2 percent of the total iodine-129 inventory. Iodine-129 levels in deer thyroids taken in the reprocessing plant locality were about 40 percent of levels of FRC guidance for human thyroids.

The evaluation of potential public health hazards from the nuclear industry has traditionally followed the philosophy and guidance developed during the fallout era, when massive amounts of fresh fission products were released into the atmosphere. This guidance has proven quite satisfactory to date, leading as it has, to a protection record that is unequaled in the development stages of any other technology. However, the rapid growth of the nuclear power industry and predictions that the growth will continue require radiation protection planning beyond the experience and guidance obtained from the days of fallout measurements.

One of the problems produced by the proliferation of nuclear power is the increase in the number of significant radionuclides in terms of exposure to man. Added to the list of potentially hazardous radionuclides from atmospheric testing of nuclear explosives are cesium-134, iodine-129, krypton-85, tritium, and activation products. While these radionuclides are not exclusively produced by nuclear power, their relative significance, in terms of exposure to man, has generally increased due to the production of nuclear power.

The evaluation of many of these newly significant radionuclides in now underway. One of these radionuclides, iodine-129, presents unique interpretive problems because of its extremely long half-life.

Predictions of natural iodine-129 concentrations in sea water, in the atmosphere, and in the terrestrial environment were made by Edward (*1*) who also discussed measurement sensitivity and the use of iodine-129 as a tracer. Results of $^{129}I/^{127}I$ measurements (*2-3*) confirm Edward's prediction that nuclear explosions have contributed substantial amounts of iodine-129 to the environment. However, iodine-129 produced by the nuclear power industry has not been widely investigated.

This paper presents a review of this potential public health problem, its possible geographical

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scope, the projected impact on population exposure, and a discussion of rather limited environmental data.

Potential hazard evaluation of iodine-129

Four characteristics of radioactive iodine-129 are important in evaluating its potential hazard to man:

1. Nuclear fission yield of approximately 1 percent, making it relatively abundant;
2. Extremely long half-life of 1.7×10^7 years, making it a permanent local, and possibly worldwide, contaminant;
3. Low beta energy and low gamma energy emitter, making detection and measurement difficult; and
4. Physiological concentration in the thyroid.

In general, there are three approaches available to evaluate the hazards of iodine-129: the Critical Pathway Approach, the Specific Activity Approach, and the Point of Discharge Approach (*4*). The Specific Activity Approach as originally developed by a National Academy of Sciences-National Research Council study (*5*) and discussed in depth by Kaye and Nelson (*6*) appears the most appropriate method and is used in this paper for reasons that will become apparent.

The specific activity may be defined as the ratio of radioactive atoms to total atoms of the same element or as activity per unit of the element (e.g. Ci/g). For this paper the definitions are:

R_t = ratio of iodine-129 atoms to total iodine atoms for a limiting dose to the thyroid as defined by International Commission on Radiological Protection and Federal Radiation Council (*7*, *8*)

SpA = curies per gram of iodine-129 (constant) $= 1.63\times10^{-4}$

lim SpA = curies of iodine-129 per gram of total iodine for a limiting dose to the thyroid as defined by the ICRP and the FRC (*7*, *8*).

The specific activity concept is based on the fact that the chemistry of radioactive and stable elements is identical. Thus, at equilibirum conditions the ratio of radioactive atoms to total atoms is constant in all media in the pathway of interest. This is the most conservative consideration in keeping with the philosophy of radiation protection since it assumes that man's total intake of iodine is from this one particular ecological chain. By using appropriate guidance (*7*) for the dose to the critical organ in man, the limiting ratio can be calculated. This concept is subject to the assumptions:

1. Identical physiological characteristics of stable and radioactive atoms of the same element;
2. Complete mixing of stable and radioactive atoms; and
3. Equilibrium conditions necessitating constant intake and discharge, relatively long half-life, etc.

In addition, sufficient information on the biological and physical parameters is needed to perform the dose analysis. The major limitation of the method is that it accounts for the dose to a critical organ from one radionuclide only and does not include organ dose from other sources (*6*).

Using ICRP recommendations (*7*) and data for standard man, the specific activity for Maximum Permissible Occupational Exposure is calculated:

$$\text{lim SpA} = \frac{(q)(f_2)}{(C)(w)}$$

where: q = maximum permissible burden of iodine-129 in the whole body (3 μCi)

f_2 = fraction in thyroid to that in whole body (0.2)

C = average concentration of stable iodine in the critical organ (350 μg/g wet tissue)

w = weight of thyroid in standard man (20 g)

The ratio of iodine-129 atoms to total iodine atoms (R_t) for the particular lim SpA is then calculated:

$$R_t = \frac{\text{lim SpA } {}^{129}\text{I}}{\text{SpA } {}^{129}\text{I}} = \frac{\text{g of } {}^{129}\text{I}}{\text{g of total iodine}}$$

These calculations have also been performed for FRC guidance (*8*) and the results are listed in table 1.

Table 1. lim SpA and R_t for iodine-129 in the 20 gram human thyroid at various recommended dose limits

Thyroid dose (rem/a)	Body burden (μCi)	Thyroid burden (μCi)	lim SpA iodine-129 (μCi/g total iodine)	R_t (iodine-129/ total iodine)
30.	3.	0.6	86.	0.53
1.5	.15	.03	4.3	.026
.5	.05	.01	1.4	.0086

From table 1, it is observed that the standard man will receive 1.5 rem/a to his thyroid if 2.6 percent of the iodine in his body is iodine-129 averaged over the year. Because the biological half-life of iodine is 138 days, a constant intake of iodine-129 is required to maintain a given ratio (R_t) in the body. It is here that the specific activity approach becomes useful. Since the ratio is assumed constant for the ecological chain, measurements can be made at any point in the chain and the potential hazard evaluated through comparisons with lim SpA or R_t ratios in table 1. This assumption is conservative since it represents the worst possible case.

This approach obviously cannot be used for intake by inhalation or in the airborne segment of the air-grass-cow-milk-man pathways because of the many complexities involved in mixing, sampling, intake, etc. However, other investigators have reported that the dose to the thyroid from iodine inhalation is small where iodine also exists in the food chain (*9,10*). The sensitivity of air sample measurements is generally low, thereby making it an inefficient sampling medium and of questionable use when attempting to establish environmental concentrations of radioactivity. It is concluded that the specific activity approach can be utilized when evaluating the chronic long-term hazards to man from iodine-129.

Production and buildup of iodine-129 from the nuclear power industry

The projected accumulated total iodine-129 produced by worldwide nuclear power from 1965 to 2060 and by United States nuclear power from 1965 to 2020 is depicted in figure 1. World power production estimates are from Coleman and Liberace (*11*), with slight modification. The total power estimate is the same but introduction of the breeder-type reactor is changed to a later date. Estimates of United States power production are from a National Air Pollution Control Administration report (*12*).

The fission yield (*13*) of iodine-129 varies by a factor of about 3 depending on the fission process. Since this variability can induce large errors in estimates of iodine-129 production, it is estimated that 40 percent of the power from uranium-235 thermal reactors is from the use of plutonium-239 while 60 percent of the power is from uranium-235. Plutonium-239 fast breeder reactors and uranium-233 thermal reactors are estimated to produce significant amounts of iodine-129 by about 1985. By 2105 more iodine-129 will be produced annually by plutonium breeder reactors than by thermal uranium-235 reactors, including the 40 percent plutonium-239 thermal contribution.

Since the decay of iodine-129 can be ignored, the long-term buildup of iodine-129 becomes appreciable. The total amount produced worldwide by 2060 will be 2 MCi, and the amount produced in 2060 will be 90 kCi. Assuming an overall removal efficiency of 99 percent, there could be 20 kCi or 120 Mg of iodine-129 in the environment in 2060. Using FRC guidance for a suitable sample of the exposed population (where lim SpA ^{129}I = 1.4 μCi/g), 14 Gg of stable iodine will be required for dilution of the iodine-129 released. Although much larger quantities of stable iodine are present in the environment, it is not known how much of this iodine would be available for dilution.

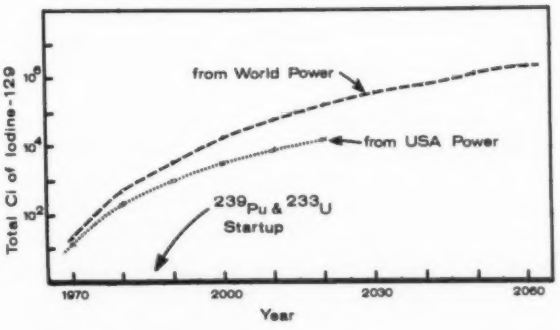

Figure 1. Accumulated iodine-129 from nuclear power

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Iodine-129 from operating reactors

Iodine-129 data are not available from operating reactors generally because most iodine-129 is removed during waste treatment procedures which also remove iodine-131. However, a method of analysis using iodine-131 measurements and an iodine-129 to iodine-131 in core concentration ratio appears feasible since it is suspected the isotopes of iodine will behave similarly. The ratio of the activities of iodine-129 to iodine-131 in core is about 10^{-8} after 1 year of operation, assuming equilibrium conditions for iodine-131. Kahn (*14*, *15*) has reported data on iodine-131 atmospheric discharges from Dresden 1 and Yankee:

Dresden 1: Iodine-131 stack discharge = 920 pCi/s = 29 mCi/a, then iodine-129 stack discharge ≈ 300 pCi/a

Yankee: Iodine-131 stack discharge = < 10 pCi/s = < 320 μCi/a, then iodine-129 stack discharge ≈ 3 pCi/a

Little significance can be attached to the Yankee iodine-131 data, since the iodine-131 results were less than the 3-sigma counting error. Kahn (*15*) concluded that no particulate or gaseous iodine-131 was detected in any sample. The relatively long holdup time in the waste gas storage tanks permitted decay of most of the iodine-131. Since the holdup time at Dresden 1 was only 30 minutes, iodine-131 decay is negligible and the estimate appears valid.

However, these small quantities appear inconsequential, and it is concluded that no public health hazard exists at the present time due to gaseous discharge of iodine-129 from nuclear power plants themselves.

Iodine-129 from an operating fuel reprocessing plant

The amount of iodine-129 present in spent fuel is about 40 mCi per metric ton (MTU) for fuel burned at 40,000 megawatt days per metric ton (MWD/MTU). Cladding integrity insures that greater than 99 percent of this activity is present before reprocessing is initiated. The nation's first commercial nuclear fuel reprocessing facility is operated by Nuclear Fuel Services, Inc. (NFS) and is located at West Valley, N.Y. Limited surveillance data for iodine-129 from this plant have been evaluated using the specific activity approach. The NFS plant routinely reports liquid waste discharges of iodine-129 (*16*). The iodine-129 discharged in the liquid waste is about 100 mCi/a, or approximately 2 percent of the total iodine-129 present in the fuel processed each year. Although this is a small percentage, it must be evaluated in context with the environmental buildup and stable iodine available for dilution, as discussed previously.

A weed sample collected in Cattaraugus Creek about 1 mile downstream of NFS discharge contained 0.81 μCi ^{129}I/g of total iodine, or 58 percent of FRC guidance for a suitable sample of an exposed population using the specific activity approach. This approach is conservative since it assumes that a man's total iodine intake would be from the ecological chain containing this weed as an integral part and that the ratio of iodine-129 to stable iodine is at equilibrium throughout the chain. Under these circumstances, the maximum dose to a man's thyroid from iodine-129 would be 58 percent of 0.5 rem/a. This finding indicates a possible concentration process as reported by others (*17*). Obviously there is a need for more information concerning the ecological behavior of iodine in aquatic systems.

Cochran et al. (*18*) have reported results of iodine-129 measurements of the gaseous waste discharge at Nuclear Fuel Services. The results of gaseous discharge samples collected during the fuel dissolution process indicate that 5 to 10 percent of the iodine-129 in each batch is discharged through the stack. Extreme caution should be used in evaluating these measurements considering:

1. The sampling was only conducted during the 4-hour dissolution process;
2. A considerable percentage of the iodine is suspected to be released during the nitric acid recovery processes; and
3. The sampling system itself suffered from many problems, such as plate-out of the iodine on the interior wall of the sampling pipe during its long run down the stack, across the roof, and into the sampling system which is inside the building.

Cochran lists additional problems.

Weighing these factors, along with the measurements, indicates that a rather high percentage of the iodine-129 is probably discharged as gaseous waste. This percentage is quite likely about 90 percent.

Mention should be made of the fact that NFS was not using their iodine removal equipment during these studies since the fuel being processed had cooled for over a year and the iodine-131 had decayed to inconsequential levels. Removal efficiency for iodine is estimated at 99.5 percent for the NFS scrubbers.

A large amount of work has been performed on the general matter of release of gaseous iodine and its subsequent behavior in the environment. The many complexities involved in evaluating the behavior of iodine in its pathways to man lead to very few general conclusions. However, it appears that a large fraction of the iodine is removed from the air within a relatively short distance from the discharge point (*10*). Thus, it is concluded that the iodine-129 released from a reprocessing plant will settle out and mix with the stable iodine within the immediate plant environs, and the gaseous iodine-129 discharge can be considered a local problem. Confirmation of this conclusion should be obtained by analyzing environmental samples from the immediate vicinity of the plant for iodine-129 and stable iodine. The immediate vicinity is within a 20-mile radius of the plant for purposes of this discussion. However, the liquid releases may have a much larger geographical impact.

The New York State Department of Health has analyzed thyroids from deer collected in the NFS environs and reports iodine-129 concentrations ranging from nondetectable to 210 pCi ^{129}I/g of thyroid for 1968 and 1969 (*19*). Assuming the same total iodine concentration in a deer thyroid as in humans, this 210 pCi/g measurement is 43 percent of FRC guidance for a suitable sample of an exposed population. Because of intake considerations, this value should not be translated in terms of human dose. It appears that a local buildup of iodine-129 is taking place around NFS. However, there is some question concerning the intake pathway of these samples since the deer have access to water from Buttermilk and Cattaraugus Creeks. Thyroid samples from cows, rabbits, groundhogs, and other animals selected from areas precluding consumption of water from the creeks may be more representative of the air pathway.

Summary and conclusions

A method of evaluating the dosimetric significance to man from iodine-129 discharged by the nuclear power industry was developed. Radiation protection recommendations of the ICRP and standard man data were used to develop an iodine-129 to total iodine ratio which can serve as a guide for evaluating environmental surveillance data at various dose levels. Estimates were made of the total iodine-129 production by the nuclear power industry on both a worldwide and a nationwide basis. Application of the method to discharge data available from operating nuclear power plants indicated that there is currently no hazard from their discharge of iodine-129. However, when the method was applied to limited surveillance data around a nuclear fuel reprocessing plant, specific activities were found to be at levels corresponding to a considerable fraction of FRC guidance for a suitable sample of the exposed population.

Since the addition of iodine-129 to the environment is an unretrievable use of natural resources, it is concluded that efforts should be undertaken to reduce the long-term accumulation of this radionuclide in the environment. In order to accomplish this reduction, information should be developed on the behavior of iodine during the various reprocessing cycles. In addition, more information is required to fully evaluate the extent of iodine-129 concentrations in environmental media around nuclear fuel reprocessing plants. The behavior of iodine in aquatic ecosystems requires investigation. When analyzing samples for iodine-129, stable iodine concentrations should also be determined in order that the specific activity approach can be used to evaluate the public health impact.

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Statistical Limits of Accuracy and Precision of Gross Alpha and Beta Radioactivity Measurements in Water

Edmond J. Baratta and *Forrest E. Knowles, Jr.*[1]

This paper presents the results of a technical experiment designed to determine the effectiveness of measurements for gross alpha and beta radioactivity in water. Since this analysis is normally used as a "screening" technique, it is essential that the limits of precision and accuracy of the method be known. Gross measurements are still being used in preoperational reactor surveys as an indication of the "background" levels and to monitor radioactivity when the reactor becomes operational. In addition, the Public Health Service standard for drinking water has, in lieu of a determination of radium-226 and strontium-90, limits for gross alpha and beta radioactivity, respectively.

The precision and accuracy of a standard method for analysis of gross alpha and beta radioactivity in water were determined through the cooperation of private and government laboratories. It was found that gross alpha radioactivity could be determined with an overall precision of 12 percent, while the gross beta radioactivity could be determined with a precision of 7 percent. The accuracy of the gross alpha activity measurements was within 10 percent, and for the gross beta activity measurements, 1 percent.

A technical experiment designed to determine the detection limits, accuracy and precision of gross alpha and beta radioactivity measurements in water was conducted by the Environmental Protection Agency's Analytical Quality Control Service at the Northeastern Radiological Health Laboratory. These analyses are normally used as a "screening" technique. Since they are used as such, it is desirable to know the limits of accuracy and precision. These measurements are routinely made by the State Health Departments and Power Companies around areas proposed as reactor sites and fuel reprocessing plants in order to establish a background survey. When the nuclear facilities become operational, the gross alpha and beta measurements are made to monitor the effluent from the plants. These are performed routinely since they are fairly inexpensive to make, as compared with specific analyses of the radionuclides present.

The Public Health Service also has found these measurements very useful as a screening technique (*1*). For guidance on drinking water, it has established an alpha limit of 3 pCi/liter and a beta limit of 10 pCi/liter before specific analyses are made. If gross alpha radioactivity is above 3 pCi/liter, then a specific analysis is made for radium-226. If gross beta radioactivity is above 10 pCi/liter, then a specific analysis is made for strontium-90.

Preparation of samples and description of test

Test materials for this experiment consisted of a standard solution of alpha radioactivity, a standard solution of beta radioactivity and tap water for a source of dissolved solids. The alpha activity was natural uranium and the beta activity was cesium-137. These solutions were dilutions of stock activity prepared in acid solution so as to eliminate loss of activity on the walls of vials. The supplied tap water was drinking water from Woburn, Mass., with a solids content of 350 mg/liter. Two pairs of samples containing different levels of radioactivity were prepared from the alpha and beta solutions. The concentrations in these samples are described in table 1.

Five ml portions of each alpha and beta solution and 4 liters of the drinking water were forwarded to the participants. In addition, cesium-

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137 and natural uranium calibration solutions were forwarded for use in preparation of absorption curves. The participants were instructed to pipet 1 ml of each alpha solution and 1 ml of each beta solution into separate appropriate aliquots of supplied water. A single analysis was to be performed for each sample.

Table 1. Radioactivity in test samples[a]

Radioactivity	Pair 1		Pair 2	
	Sample R	Sample S	Sample T	Sample U
Alpha (pCi natural U/sample[b])	37.9	25.4	100.2	80.5
Beta (pCi ^{137}Cs/sample)	62.5	47.7	130.0	156.0

[a] The accuracy of the standards were within ±2 percent.
[b] pCi/sample refers to picocuries per 1 milliliter of supplied alpha and beta activity.

Methodology

Procedures used to measure the gross alpha and gross beta activities were taken from the 12th Edition of the American Public Health Association (APHA) Standard Methods (*2*). Analysis of gross alpha and beta radioactivity is as follows: The specific conductance is measured first to help select the proper sample volume. The sample is prepared by (1) adding sample directly to a tared counting pan with evaporation just below the boiling temperature, or (2) placing the sample in a pyrex beaker, adjusting the pH to 4–6, and evaporating to near dryness. The residue is transferred to a tared counting pan using water and dilute acid washings.

The counting pan is dried in an oven at 103–105° C, cooled in a desiccator, weighed, and kept dry until counted. The sample is counted in an internal proportional counter or other appropriate counting instrument.

Analysis of data

The results of the gross alpha test are presented in table 2. The results of the gross beta test are presented in table 3. The design and evaluation of these tests are based in part on Youden's guide on "Statistical Techniques for Collaborative Tests" (*3*). This design assumes that the internal precision is not different at each laboratory, and the differences which usually exist between laboratories are associated with laboratory systematic errors.

Table 2. Gross alpha radioactivity in water

Laboratory code[a]	Results (pCi/sample)			
	Sample R	Sample S	Sample T	Sample U
E	40.4	28.3	97.3	78.8
G	14.9	10.6	34.9	31.7
I	34.0	23.8	91.4	73.8
J	35.5	21.5	90.7	77.5
M	35.3	26.4	83.2	65.2
N	57.8	34.6	155.7	112.0
O	24.2	20.5	44.7	25.0
Q	34.8	25.3	85.4	76.7
R	33.0	22.8	65.0	67.6
S	15.1	12.3	53.4	28.4
T	36.1	24.0	97.3	78.8
V	48.3	29.5	135.7	107.8
X	42.1	27.2	120.8	89.8
Y[b]	4.63	3.58	15.6	11.3
Average	34.7	23.6	88.9	70.2
Range	42.9	24.0	120.8	87.0
Known	37.9	25.4	100.2	80.5

[a] Laboratory code P and AA did not participate in this analysis.
[b] Not included in range or average.

Table 3. Gross beta radioactivity in water

Laboratory code	Results (pCi/sample)			
	Sample R	Sample S	Sample T	Sample U
E	67.5	54.1	146.0	168.8
G	39.2	46.6	54.5	116.0
I	43.2	39.6	108.5	139.6
J	62.0	49.6	125.5	155.3
M	93.5	78.4	217.0	234.0
N	78.8	65.2	170.7	200.4
O	50.7	34.4	111.2	119.7
P	68.8	45.5	131.0	156.0
Q	66.8	51.7	135.3	157.1
R	61.6	52.6	125.4	151.2
S	64.2	49.5	126.3	142.8
T	65.4	51.5	127.4	155.0
V	55.4	45.4	118.2	152.7
X	59.9	48.6	128.2	154.4
Y	49.3	39.0	103.0	122.0
AA	59.5	47.4	134.9	152.0
Average	61.6	49.9	128.9	154.8
Range	54.3	44.0	162.5	118.0
Known	62.5	47.7	130.0	156.0

There are three distributions which are of interest: S_d—the combined effect of the distribution of systematic errors and the random errors associated with the individual results. S_s—a

measure of how successful repeat determinations can be made (degree of random error). S_b—a measure of the displacement (or change in bias) that may be encountered as one changes laboratories (or degree of laboratory systematic error). The distribution has the following relationship:

$$S_d^2 = S_b^2 + S_a^2 \qquad \ldots(1)$$

The actual data yield S_d^2 and S_a^2. S_b^2 is determined by difference. The following formulas were used to make the various calculations:

$$S_d = \sqrt{\frac{(T_i - \overline{T})^2}{2(n-1)}} \qquad \ldots(2)$$

T_i = Total of the paired samples for the "i"th lab
$\overline{T}$ = average total
n = number of totals

$$S_a = \sqrt{\frac{(D_i - \overline{D})^2}{2\,(n-1)}} \qquad \ldots(3)$$

D_i = difference between paired samples for the "i"th lab
$\overline{D}$ = average difference
n = number of differences

An estimate of the method accuracy is obtained by the difference between the average known concentration and the average found concentration for each pair. The relative accuracy is calculated by dividing this difference by the average known concentration. Relative precision for the method is estimated by dividing the random error (S_a) by the average amount found for each pair. This statistical analysis for the gross alpha and beta radioactivity is presented in tables 4 and 5, respectively. The summary for gross alpha and beta radioactivity is presented in table 6.

Discussion of results

Accuracy and precision for this method were determined using the data from all contributing laboratories except in the case of gross alpha radioactivity where one outlying laboratory was not included. For both alpha and beta determinations, there were some laboratories which could have been excluded from the data analysis due to their deviation from the known but were included to keep the number of laboratories at a maximum.

The gross alpha determination appears to be biased low, as observed from the differences the average amount present and the average amount found. The accuracy ranges from minus 8 percent to 12 percent and the precision ranges from 11 percent to 14 percent. In most cases the laboratories did quite well in determining the difference between the paired samples. In the

Table 4. Data analysis, gross alpha radioactivity in water

Laboratory code[a]	Difference (R−S)	Total (R+S)	Difference (T−U)	Total (T+U)
Known	12.5	63.3	19.7	180.7
E	12.1	68.7	18.5	176.1
G	4.3	25.5	3.2	66.6
I	10.2	57.8	17.6	165.2
J	14.0	57.0	13.2	168.2
M	8.9	61.7	18.0	148.4
N	23.2	92.4	43.7	267.7
O	3.7	44.7	19.7	69.7
Q	9.5	60.1	8.7	162.1
R	10.2	55.8	−2.6	132.6
S	2.8	27.4	25.0	81.8
T	12.1	60.1	18.5	176.1
V	18.8	77.8	27.9	243.5
X	14.9	69.3	31.0	210.6
Total	144.7	758.3	242.4	2,068.6
Average	11.1	58.3	18.6	159.1
S_a^2	17.1		72.0	
S_a	4.1		8.5	
S_d^2		167.3		1,901
S_d		12.9		43.6

[a] Laboratory Y was not included in data analysis.

Table 5. Data analysis, gross beta radioactivity in water

Laboratory code	Difference (R−S)	Total (R+S)	Difference (U−T)	Total (U+T)
Known	14.8	110.2	26.0	286.0
E	13.4	121.6	22.8	314.8
G	−7.4	85.8	61.5	170.5
I	3.6	82.8	31.1	248.1
J	12.4	111.6	29.8	280.8
M	15.1	171.9	17.0	451.0
N	13.6	144.0	29.7	371.1
O	16.3	85.1	8.5	230.9
P	23.3	114.3	25.0	287.0
Q	15.1	118.5	21.8	292.4
R	9.0	114.2	25.8	276.6
S	14.7	113.7	16.5	269.1
T	13.9	116.9	27.6	282.4
V	10.0	100.8	34.5	270.9
X	11.3	108.5	26.2	282.6
Y	10.3	88.3	19.0	225.0
AA	12.1	106.9	17.1	286.9
Total	186.7	1,784.9	413.9	4,540.1
Average	11.7	111.6	25.8	283.8
S_a^2	21.4		67.5	
S_a	4.6		8.2	
S_d^2		259.0		1,914.9
S_d		16.1		43.8

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Table 6. Summary of results

Pair	Average amount found	Average amount present	Difference amount present-amount found	S_a	$\frac{S_a \times 100}{\text{Average amount found}}$
Gross alpha radioactivity in water:					
1	29.2	31.7	2.5	4.1	14.0
2	79.6	90.4	10.8	8.5	10.7
Gross beta radioactivity in water:					
1	55.8	55.1	−0.7	4.6	8.2
2	141.9	143.0	1.1	8.2	5.8

absence of laboratory systematic error, S_a and S_d are estimates of the same within laboratory precision. S_a is substantially smaller than S_d for sample pairs which indicates the presence of some degree of laboratory systematic error. Possible explanations for the low bias are (1) problems in self-absorption since some laboratories experienced excessive weights of solids, and (2) incomplete drying of samples.

The gross beta results did not show any bias. The average amount present and average amount found were nearly identical for both pairs. The accuracy is about 1 percent and the precision ranges from 6 percent to 8 percent. The laboratories did well in determining the differences between the paired samples. Laboratory systematic errors are present in some degree since S_a is substantially less than S_d for both sample pairs. Problems in solids preparation were experienced by some of the laboratories but did not appear to be serious.

The results of the technical experiment show that this procedure for gross alpha and beta determination is acceptable as a standard method. As a screening technique, the procedure performed better than expected and could be applied to limits for specific radionuclides. The only problem appears to be in amount of solids present but if the suggested aliquot size and drying technique is followed carefully, it should not be serious.

Samples with activities around 3 pCi/liter for alpha and 10 pCi/liter for beta have not been used for a technical experiment. These levels have been used in the Analytical Quality Control Service cross-check water program. (*4*) The results of samples in that program with activities similar to the samples in this technical experiment have been comparable.

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SECTION I. MILK AND FOOD

Milk Surveillance, December 1970

Although milk is only one of the sources of dietary intake of environmental radioactivity, it is the food item that is most useful as an indicator of the general population's intake of radionuclide contaminants resulting from environmental releases. Fresh milk is consumed by a large segment of the population and contains several of the biologically important radionuclides that may be released to the environment from nuclear activities. In addition, milk is produced and consumed on a regular basis, is convenient to handle and analyze, and samples representative of general population consumption can be readily obtained. Therefore, milk sampling networks have been found to be an effective mechanism for obtaining information on current radionuclide concentrations and long-term trends. From such information, public health agencies can determine the need for further investigation or corrective public health action.

The Pasteurized Milk Network (PMN) sponsored by the Radiation Office, Environmental Protection Agency, and the Office of Food Sanitation, Food and Drug Administration, U.S. Public Health Service, consists of 63 sampling stations; 61 located in the United States, one in Puerto Rico, and one in the Canal Zone. Many of the State Health departments also conduct local milk surveillance programs which provide more comprehensive coverage within the individual State. Data from 15 of these State networks are reported routinely in *Radiological Health Data and Reports*. Additional networks for the routine surveillance of radioactivity in milk in the Western Hemisphere and their sponsoring organizations are:

Pan American Milk Sampling Program (Pan American Health Organization and U.S. Environmental Protection Agency)—5 sampling stations

Canadian Milk Network (Radiation Protection Division, Canadian Department of National Health and Welfare)—16 sampling stations

The sampling locations that make up the networks presently reporting in *Radiological Health Data and Reports* are shown in figure 1. Based on the similar purpose for these sampling activities, the present format integrates the complementary data that are routinely obtained by these several milk networks.

Radionuclide and element coverage

Considerable experience has established that relatively few of the many radionuclides that are formed as a result of nuclear fission become incorporated in milk (*1*). Most of the possible radiocontaminants are eliminated by the selective metabolism of the cow, which restricts gastrointestinal uptake and secretion into the milk. The five fission-product radionuclides which commonly occur in milk are strontium-89, strontium-90, iodine-131, cesium-137, and barium-140. A sixth radionuclide, potassium-40, occurs naturally in 0.0118 percent (*2*) abundance of the element potassium, resulting in a specific activity for potassium-40 of 830 pCi/g total potassium.

Two stable elements which are found in milk, calcium and potassium, have been used as a means for assessing the biological behavior of

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Figure 1. Milk sampling networks in the Western Hemisphere

metabolically similar radionuclides (radiostrontium and radiocesium, respectively). The contents of both calcium and potassium in milk have been measured extensively and are relatively constant. Appropriate values and their variations, expressed in terms of 2-standard deviations (2σ), for these elements are 1.16 ± 0.08 g/liter for calcium and 1.51 ± 0.21 g/liter for potassium. These figures are averages of data from the PMN for May 1963–March 1966 (*3*) and were determined for use in general radiological health calculations or discussions.

Accuracy of data from various milk networks

In order to combine data from the international, national, and State networks considered in this report, it was first necessary to determine the accuracy with which each laboratory is making its determinations and the agreement of the measurements among the laboratories. The Analytical Quality Control Service of the Bureau of Radiological Health conducts periodic studies to assess the accuracy of determinations of radionuclides in milk performed by interested public health radiochemical laboratories. The generalized procedure for making such a study has been outlined previously (*4*).

The most recent study was conducted during May–July 1970, with 28 laboratories participating in an experiment on milk samples containing known concentrations of strontium-89, strontium-90, iodine-131,cesium-137, and barium-140 (*5*). Of the 20 laboratories producing data for the networks reporting in *Radiological Health Data and Reports*, 13 participated in the experiment.

The accuracy results of this experiment are shown in table 1. In general, considerable improvement is needed, especially in the accuracy measurements. These possible differences should be kept in mind when considering the integration of data from the various networks.

Development of a common reporting basis

Since the various networks collect and analyze differently, a complete understanding of several parameters is useful for interpreting the data. Therefore, the various milk surveillance networks that report regularly were surveyed for information on analytical methods, sampling and analysis frequencies, and estimated analytical errors associated with the data.

In general, radiostrontium is collected by an ion-exchange technique and determined by beta-particle counting in low-background detectors, and the gamma-ray emitters (potassium-40, iodine-131, cesium-137, and barium-140) are determined by gamma-ray spectroscopy of whole

Table 1. Distribution of mean results, quality control experiment

Isotope and known concentration	Number of laboratories in each category			
	Acceptable[a]	Warning level[b]	Unacceptable[c]	Total
Strontium-89: High (258 pCi/liter)	7 (44%)	1 (6%)	8 (50%)	16
Low (15 pCi/liter)	11 (69%)	3 (19%)	2 (12%)	16
Strontium-90: Intermediate (79.4 pCi/liter)	13 (57%)	4 (17%)	6 (26%)	23
Low (32.0 pCi/liter)	5 (25%)	4 (20%)	11 (55%)	20
Iodine-131: High (507 pCi/liter)	18 (67%)	2 (7%)	7 (26%)	27
Low (49 pCi/liter)	16 (64%)	3 (12%)	6 (24%)	25
Cesium-137: High (259 pCi/liter)	20 (74%)	3 (11%)	4 (15%)	27
Low (53 pCi/liter)	17 (66%)	5 (19%)	4 (15%)	26
Barium-140: High (302 pCi/liter)	18 (67%)	2 (7%)	7 (26%)	27
Low (33 pCi/liter)	23 (92%)	0	2 (8%)	25

[a] Measured concentration less than or equal to 2σ of the known concentration.
[b] Measured concentration greater than 2σ and less than or equal to 3σ of the known concentration.
[c] Measured concentration greater than 3σ of the known concentration.

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milk. Each laboratory has its own modifications and refinements of these basic methodologies. The methods used by each of the networks have been referenced in earlier reports appearing in *Radiological Health Data and Reports.*

A previous article (*6*) summarized the criteria used by the State networks in setting up their milk sampling activities and their sample collection procedures as determined during a 1965 survey. This reference and earlier data article for the particular network of interest may be consulted should events require a more definitive analysis of milk production and milk consumption coverage afforded by a specific network.

Many networks collect and analyze samples on a monthly basis. Some collect samples more frequently but composite the several samples for one analysis, while others carry out their analyses more often than once a month. Many networks are analyzing composite samples on a quarterly basis for certain nuclides. The frequency of collection and analysis varies not only among the networks but also at different stations within some of the networks. In addition, the frequency of collection and analysis is a function of current environmental levels. The number of samples analyzed at a particular sampling station under current conditions is reflected in the data presentation. Current levels for strontium-90 and cesium-137 are relatively stable over short time periods, and sampling frequency is not critical. For the short-lived radionuclides, particularly iodine-131, the frequency of analysis is critical and is generally increased at the first measurement or recognition of a new influx of this radionuclide.

The data presentation also reflects whether raw or pasteurized milk was collected. An analysis (*7*) of raw and pasteurized milk samples collected during January 1964 to June 1966 indicated that, for relatively similar milkshed or sampling areas, the differences in concentration of radionuclides in raw and pasteurized milk are not statistically significant(*7*). Particular attention was paid to strontium-90 and cesium-137 in that analysis.

Practical reporting levels were developed by the participating networks, most often based on 2-standard deviation counting errors or 2-standard deviation total analytical errors from replicate analyses (*3*). The practical reporting level reflects analytical factors other than statistical radioactivity counting variations and will be used as a practical basis for reporting data.

The following practical reporting levels have been selected for use by all networks whose practical reporting levels were given as equal to or less than the given value.

Radionuclide	Practical reporting level (pCi/liter)
Strontium-89	5
Strontium-90	2
Iodine-131	10
Cesium-137	10
Barium-140	10

Some of the networks gave practical reporting levels greater than those above. In these cases, the larger value is used so that only data considered by the network as meaningful will be presented. The practical reporting levels apply to the handling of individual sample determinations. The treatment of measurements equal to or below these practical reporting levels for calculation purposes, particularly in calculating monthly averages, is discussed in the data presentation.

Analytical error or precision expressed as pCi/liter or percent in a given concentration range have also been reported by the networks (*3*). The precision errors reported for each of the radionuclides fall in the following ranges:

Radionuclide	Analytical errors of precision (2-standard deviations)
Strontium-89	1–5 pCi/liter for levels <50 pCi/liter; 5–10% for levels ≥50 pCi/liter;
Strontium-90	1–2 pCi/liter for levels <20 pCi/liter; 4–10% for levels ≥20 pCi/liter;
Iodine-131, Cesium-137, Barium-140	4–10 pCi/liter for levels <100 pCi/liter; 4–10% for levels ≥100 pCi/liter.

For iodine-131, cesium-137, and barium-140, there is one exception for these precision error ranges: 25 pCi/liter at levels <100 pCi/liter for Colorado. This is reflected in the practical reporting level for the Colorado milk network.

Federal Radiation Council guidance applicable to milk surveillance

In order to place the U.S. data on radioactivity in milk presented in *Radiological Health Data and Reports* in perspective, a summary of the guidance provided by the Federal Radiation Council for specific environmental conditions was presented in the December 1970 issue of *Radiological Health Data and Reports.*

Data reporting format

Table 2 presents the integrated results of the international, national, and State networks discussed earlier. Column 1 lists all the stations which are routinely reported to *Radiological Health Data and Reports.* The relationship between the PMN stations and the State stations is shown in figure 2. The first column under each of the reported radionuclides gives the monthly average for the station and the number of samples analyzed in that month in parentheses. When an individual sampling result is equal to or below the practical reporting level for the radionuclide, a value of zero is used for averaging. Monthly averages are calculated using the above convention. Averages which are equal to or less than the practical reporting levels reflect the presence of radioactivity in some of the individual samples greater than the practical reporting level.

The second column under each of the radionuclides reported gives the 12-month average for the station as calculated from the preceding 12 monthly averages, giving each monthly average equal weight. Since the daily intake of radioactivity by exposed populations groups, averaged over a year, constitutes an appropriate criterion for the case where the FRC radiation protection guides apply, the 12-month average serves as a basis for comparison.

Discussion of current data

In table 2, surveillance results are given for strontium-90, iodine-131, and cesium-137 for December 1970 and the 12-month period, January 1970 to December 1970. Except where noted, the

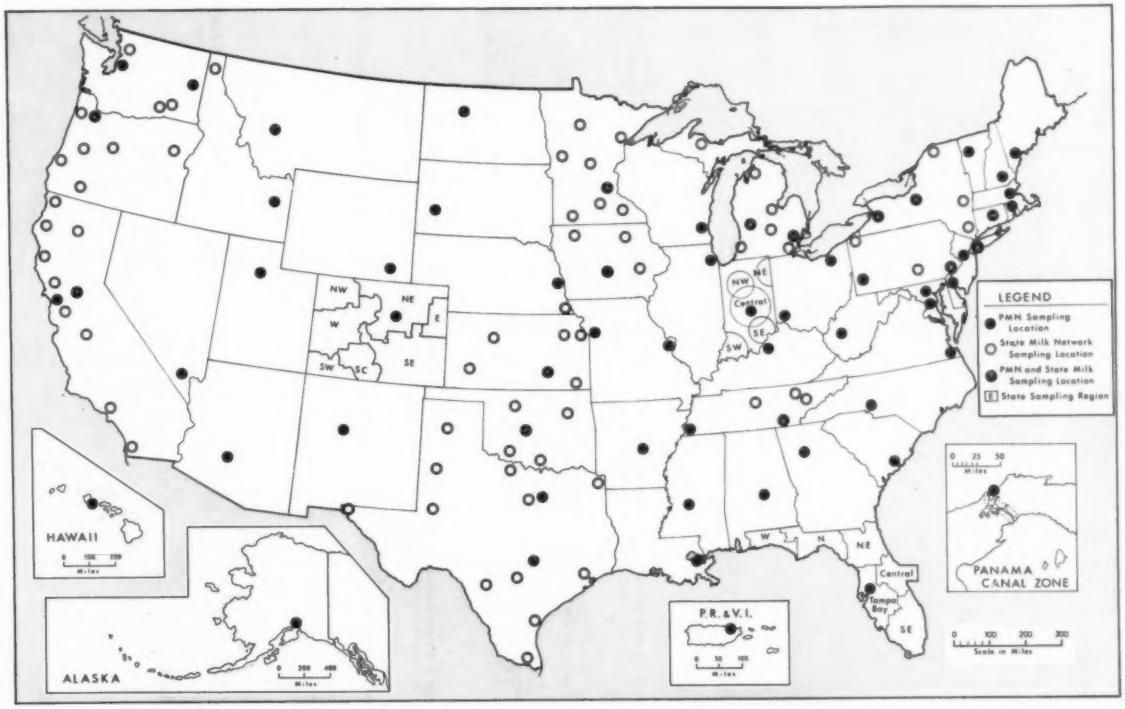

Figure 2. State and PMN milk sampling locations in the United States

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Table 2. Concentrations of radionuclides in milk for December 1970 and 12-month period, January 1970 through December 1970

Sampling location		Type of sample[a]	Radionuclide concentration (pCi/liter)					
			Strontium-90		Iodine-131		Cesium-137	
			Monthly average[b]	12-month average	Monthly average[b]	12-month average	Monthly average[b]	12-month average
UNITED STATES:								
Ala:	Montgomery[c]	P	NA	6	0	0	0	8
Alaska:	Palmer[c]	P	4	6	0	0	0	9
Ariz:	Phoenix[c]	P	NA	1	0	0	0	0
Ark:	Little Rock[c]	P	12	13	0	0	0	15
Calif:	Sacramento[c]	P	NA	2	0	0	0	0
	San Francisco[c]	P	NA	2	0	0	0	0
	Del Norte	P	10	17	0	0	13	15
	Fresno	P	2	2	0	0	0	1
	Humboldt	P	6	5	0	0	0	5
	Los Angeles	P	2	2	0	0	0	2
	Mendocino	P	3	3	0	0	0	2
	Sacramento	P	3	3	0	0	0	2
	San Diego	P	2	2	0	0	0	1
	Santa Clara	P	2	2	0	0	0	1
	Shasta	P	2	3	0	0	0	2
	Sonoma	P	2	3	0	0	0	2
Colo:	Denver[c]	P	5 (2)	5	0 (3)	0	0 (3)	1
	West	R	(d)		(e)0 (10)	(e)0	(e)0 (10)	(e)3
	Northeast	R	(d)		(e)0 (4)	(e)0	(e)0 (4)	(e)0
	East	R	(d)		(e)0 (2)	(e)0	(e)0 (2)	(e)0
	Southeast	R	(d)		(e)0	(e)0	(e)0	(e)0
	South Central	R	(d)		NS	NS	NS	NS
	Southwest	R	(d)		(e)0	(e)0	(e)0	(e)0
	Northwest	R	(d)		(e)0	(e)0	(e)0	5
Conn:	Hartford[c]	P	NA	8	0	0	16	11
	Central	P	NA	7	0	0	10	14
Del:	Wilmington[c]	P	NA	9	0	0	0	7
D.C:	Washington[c]	P	NA	7	0	0	11	7
Fla:	Tampa[c]	P	6	6	0	0	53	51
	West	R	6	9	0	0	20	17
	North	R	14	12	0	0	30	26
	Northeast	R	6	6	0	0	39	40
	Central	R	8	7	0	0	44	49
	Tampa Bay area	R	6	6	0	0	51	50
	Southeast	R	7	7	0	0	43	75
Ga:	Atlanta[c]	P	NA	11	0	0	0	14
Hawaii:	Honolulu[c]	P	3	2	0	0	0	0
Idaho:	Idaho Falls[c]	P	5 (3)	5	0 (3)	0	4 (3)	6
Ill:	Chicago[c]	P	6	7	0	0	19	11
Ind:	Indianapolis[c]	P	NA	8	0	0	0	6
	Northeast	P	10	10	0	1	10	13
	Southeast	P	9	11	0	0	10	12
	Central	P	8	9	40	3	15	10
	Southwest	P	14	12	0	0	0	11
	Northwest	P	10	11	0	0	0	13
Iowa:	Des Moines[c]	P	NA	7	0	0	0	2
	Iowa City	P	8	8	0 (2)	0	19 (2)	12
	Des Moines	P	6	8	0 (4)	0	15 (4)	9
	Spencer	P	4	6	0	0	0	7
	Fredericksburg	P	NS	NS	NS	NS	NS	NS
Kans:	Wichita[c]	P	NA	8	0	0	0	3
	Coffeyville	P	7	9	0	2	12	2
	Dodge City	P	9	7	0	0	0	1
	Falls City	R	NS	13	NS	3	NS	4
	Hays	P	NS	13	NS	2	NS	1
	Kansas City	P	8	8	0	0	13	5
	Topeka	P	8	10	0	2	14	4
	Wichita	P	12	12	0	0	0	1
Ky:	Louisville[c]	P	NA	9	0	0	0	4
La:	New Orleans[c]	P	14	14	0	0	11	19
Maine:	Portland[c]	P	NA	10	0	0	19	22
Md:	Baltimore[c]	P	NA	7	0	0	0	6
Mass:	Boston[c]	P	8	10	0	0	11	20
Mich:	Detroit[c]	P	NA	9	0	0	11	9
	Grand Rapids[c]	P	NA	9	0	0	21	12
	Bay City	P	NS	7	NS	(e)0	NS	11
	Charlevoix	P	NA	13	(e)0 (4)	1	14 (4)	16
	Detroit	P	NA	8	(e)0	(e)0	0	8
	Grand Rapids	P	NA	9	(e)0	(e)0	0	8
	Lansing	P	NA	9	(e)0 (2)	(e)0	14 (2)	14
	Marquette	P	NA	14	(e)0 (2)	(e)0	21 (2)	23
	Monroe	P	NA	6	(e)0 (2)	(e)0	0 (2)	3
	South Haven	R	NA	8	(e)0 (4)	(e)0	0 (4)	6
Minn:	Minneapolis[c]	P	NA	9	0	0	0	10
	Bemidji	P	8	9	0	0	18	21
	Mankato	P	5	5	0	0	9	11
	Rochester	P	7	6	0	0	14	12
	Duluth	P	NS	14	NS	0	NS	27
	Worthington	P	5	4	0	0	0	0
	Minneapolis	P	11	9	0	0	23	17

See footnotes at end of table.

Table 2. Concentrations of radionuclides in milk for December 1970 and 12-month period, January 1970 through December 1970—Continued

Sampling location		Type of sample[a]	Radionuclide concentration (pCi/liter)					
			Strontium-90		Iodine-131		Cesium-137	
			Monthly average[b]	12-month average	Monthly average[b]	12-month average	Monthly average[b]	12-month average
UNITED STATES—Continued								
Minn:	Fergus Falls	P	6	5	0	0	0	13
	Little Falls	P	4	11	0	0	14	33
Miss:	Jackson[c]	P	NA	12	0	0	0	11
Mo:	Kansas City[c]	P	NA	8	0	0	0	2
	St. Louis[c]	P	NA	8	0	0	0	4
Mont:	Helena[c]	P	NA	5	0	0	20	7
Nebr:	Omaha [c]	P	NA	5	0	0	0	1
Nev:	Las Vegas[c]	P	NA	3	0	0	0	0
N.H:	Manchester[c]	P	NA	9	0	0	26	19
N.J:	Trenton[c]	P	NA	8	0	0	14	9
N.Mex:	Albuquerque[c]	P	NA	3	0	0	0	0
N.Y:	Buffalo[c]	P	6	7	0	0	16	10
	New York City[c]	P	NA	10	0	0	17	17
	Syracuse[c]	P	NA	7	0	0	21	10
	Albany	P	7	7	0 (5)	0	(e)0 (5)	(e)0
	Buffalo	P	(e)0	(e)0	0	0	(e)0	(e)0
	Massena	P	8	7	0 (2)	0	25 (2)	20
	Newburg	P	5	7	0 (5)	0	20 (5)	(e)0
	New York City	P	(e)0	9	0	0	(e)0	(e)0
	Syracuse	P	5	4	0 (2)	0	0 (2)	(e)0
N.C:	Charlotte[c]	P	NS	11	NS	0	NS	13
N.Dak:	Minot[c]	P	NA	10	0	0	0	12
Ohio:	Cincinnati[c]	P	NA	7	0	0	0	3
	Cleveland[c]	P	NA	9	0	0	16	11
Okla:	Oklahoma City[c]	P	NA	7	0	0	0	5
	Oklahoma City	P	NS		NS		NS	
	Enid	P	NS		NS		NS	
	Tulsa	P	NS		NS		NS	
	Lawton	P	NS		NS		NS	
	Ardmore	P	NS		NS		NS	
Oreg:	Portland[c]	P	6	6	0	0	11	5
	Baker	P	NA	4	(e)0	(e)0	17	6
	Coos Bay	P	NA	6	(e)0	(e)0	22	12
	Eugene	P	NA	3	(e)0	(e)0	(e)0	3
	Medford	P	NA	3	(e)0	(e)0	(e)0	8
	Portland composite	P	NA	5	(e)0	(e)0	(e)0	8
	Portland local	P	NA	5	(e)0	(e)0	12	7
	Redmond	P	3	4	(e)0	(e)0	(e)0	2
	Tillamook	R	NA	7	(e)0	(e)0	(e)0	16
Pa:	Philadelphia[c]	P	NA	9	0	0	17	7
	Pittsburgh[c]	P	NA	11	0	0	12	13
	Dauphin	P	8	8	0	2	14	11
	Erie	P	NS	11	NS	3	NS	25
	Philadelphia	P	8	8	0	0	15	14
	Pottsburgh	P	11	13	0	1	26	20
R.I:	Providence[c]	P	NA	9	0	0	16	17
S.C:	Charleston[c]	P	9	9	0	1	13	18
S.Dak:	Rapid City[c]	P	NS	7	NS	0	NS	5
Tenn:	Chattanooga[c]	P	NA	10	0	0	11	10
	Memphis[c]	P	NA	9	0	0	0	6
	Chattanooga	P	8	9	0	0	17	14
	Clinton	P	8	12	0	0	15	14
	Knoxville	P	4	7	10 (2)	0	12 (2)	11
	Nashville	P	5	6	0	0	18	10
	Fayetteville	P	10	12	0	0	22	14
Tex:	Austin[c]	P	NA	3	0	0	0	3
	Dallas[c]	P	NA	7	0	0	14	7
	Amarillo	R	NS		NS		NS	
	Corpus Christi	R	NS		NS		NS	
	El Paso	R	NS		NS		NS	
	Fort Worth	R	NS		NS		NS	
	Harlingen	R	NS		NS		NS	
	Houston	R	NS		NS		NS	
	Lubbock	R	NS		NS		NS	
	Midland	R	NS		NS		NS	
	San Antonio	R	NS		NS		NS	
	Texarkana	R	NS		NS		NS	
	Tyler	R	NS		NS		NS	
	Uvalde	R	NS		NS		NS	
	Wichita Falls	R	NS		NS		NS	
Utah:	Salt Lake City[c]	P	5 (2)	4	0 (2)	0	16 (2)	8
Vt:	Burlington[c]	P	NA	8	0	0	19	13
Va:	Norfolk[c]	P	NA	9	0	0	14	8
Wash:	Seattle[c]	P	NA	5	0	0	0	3
	Spokane[c]	P	NA	5	0	0	0	2
	Benton County	R	NS	0	NS	0	NS	5
	Franklin County	R	8	2	0	0	14	6
	Sandpoint, Idaho	R	14	11	0	0	21	21
	Skagit County	R	6	6	0	0	12	9

See footnotes at end of table.

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Table 2. Concentrations of radionuclides in milk for December 1970 and 12-month period, January 1970 through December 1970—Continued

Sampling location	Type of sample[a]	Radionuclide concentration (pCi/liter)					
		Strontium–90		Iodine–131		Cesium–137	
		Monthly average[b]	12-month average	Monthly average[b]	12-month average	Monthly average[b]	12-month average
UNITED STATES—Continued							
W.Va: Charleston[c]	P	NA	8	0	0	11	5
Wisc: Milwaukee[c]	P	NA	6	0	0	19	11
Wyo: Laramie[c]	P	5 (2)	5	0 (4)	0	6 (4)	1
CANADA:							
Alberta: Calgary	P	6	7	[d]		22	18
Edmonton	P	6	7	[d]		27	20
British Columbia: Vancouver	P	7	9	[d]		27	25
Manitoba: Winnipeg	P	7	7	[d]		21	24
New Brunswick: Fredericton	P	12	12	[d]		23	23
Newfoundland: St. John's	P	10	17	[d]		17	35
Nova Scotia: Halifax	P	15	12	[d]		21	21
Ontario: Ottawa	P	7	6	[d]		16	14
Sault Ste. Marie	P	12	13	[d]		30	32
Thunder Bay	P	12	12	[d]		22	25
Toronto	P	4	9	[d]		15	10
Windsor	P	4	5	[d]		18	11
Quebec: Montreal	P	7	7	[d]		18	18
Quebec	P	9	9	[d]		31	27
Saskatchewan: Regina	P	8	7	[d]		13	14
Saskatoon	P	9	9	[d]		22	15
CENTRAL AND SOUTH AMERICA:							
Colombia: Bogota	P	2	0	0	0	0	0
Chile: Santiago	P	0	0	0	0	0	0
Ecuador: Guayaquil	P	0	0	0	0	0	0
Jamaica: Kingston	P	NS	5	NS	0	NS	76
Venezuela: Caracas	P	3	1	0	0	0	0
Canal Zone: Cristobal[c]	P	NA	1	0	0	14	10
Puerto Rico: San Juan[c]	P	NA	4	0	0	0	7
PMN Network average[f]		7	7	0	0	8	9

[a] P, pasteurized milk.
R, raw milk.

[b] When an individual sampling result was equal to or less than the practical reporting level, a value of "0" was used for averaging. Monthly averages less than the practical reporting level reflect the fact that some but not all of the individual samples making up the average contained levels greater than the practical reporting level. When more than one analysis was made in a monthly period, the number of samples in the monthly average is given in parentheses.

[c] Pasteurized Milk Network station. All other sampling locations are part of the State or National network.

[d] Radionuclide analysis not routinely performed.

[e] The practical reporting levels for these networks differ from the general ones given in the text. Sampling results for the networks were equal to or less than the following practical reporting levels:

Iodine-131: Colorado–25 pCi/liter; Michigan–14 pCi/liter; Oregon–15 pCi/liter
Cesium-137: Colorado–25 pCi/liter; New York–20 pCi/liter; Oregon–15 pCi/liter
Strontium-90: New York–3 pCi/liter

[f] This entry gives the average radionuclide concentrations for the Pasteurized Milk Network stations denoted by footnote [e].
NA, no analysis.
NS, no sample collected.

monthly average represents a single sample for the sampling station. Strontium-89 and barium-140 data have been omitted from table 2 since levels at the great majority of the stations for December 1970 were below the respective practical reporting levels. The following station average reflects a sample in which strontium-89 was detected: Ark., Little Rock (PMN), 10 pCi/liter; Fla., Tampa (PMN), 8 pCi/liter; Kans., Kansas City (State), 7 pCi/liter; S.C., Charleston (PMN), 8 pCi/liter.

Iodine-131 results are included in the table, even though they were generally below practical reporting levels. Because of the lower values

reflected by the radiation protection guidance provided by the Federal Radiation Council, levels in milk for this radionuclide are of particular public health interest. In general, the practical reporting level for iodine-131 is numerically equal to the upper value of Range I (10 pCi/liter) of the FRC radiation protection guide.

Strontium-90 monthly averages ranged from 0 to 14 pCi/liter in the United States for the month of December 1970, and the highest 12-month average was 17 pCi/liter (Del Norte, Calif.) representing 8.5 percent of the Federal Radiation Council radiation protection guide. Cesium-137 monthly averages ranged from 0 to 53 pCi/liter in the United States for December 1970, and the highest 12-month average was 75 pCi/liter (Southeast Florida), representing 2.1 percent of the value determined by using the recommendations given in the Federal Radiation Council reports. Of particular interest are the consistently higher cesium-137 levels that have been observed in Florida (*8*) and Jamaica. Iodine-131 results for individual samples were all below the practical reporting level, with the exception of Central (State) Indiana, 40 pCi/liter. This sample was collected December 4, 1970.

Special milk samples from the PMN were taken at Denver, Colo; Idaho Falls, Idaho; Salt Lake City, Utah; and Laramie, Wyo., because of an unplanned release of radioactive material from an underground nuclear weapons test at the Nevada Test site on December 18, 1970. Fresh fission products were not detected at any of the PMN stations following this event.

Acknowledgement

Appreciation is expressed to the personnel of the following agencies who provide data for their milk surveillance networks:

Bureau of Radiological Health
Division of Environmental Sanitation
California State Department of Health

Radiation Protection Division
Canadian Department of National Health and Welfare

Radiological Health Section
Division of Occupational and Radiological Health
Colorado State Department of Health

Radiological Health Services
Division of Medical Services
Connecticut State Department of Health

Radiological and Occupational Health Section
Department of Health and Rehabilitative Services
State of Florida

Bureau of Environmental Sanitation
Division of Sanitary Engineering
Indiana State Board of Health

Division of Radiological Health
Environmental Engineering Services
Iowa State Department of Health

Radiation Control Section
Environmental Health Division
Kansas State Department of Health

Radiological Health Services
Division of Occupational Health
Michigan Department of Health

Radiation Control Section
Division of Environmental Health
State of Minnesota Department of Health

Bureau of Nuclear Engineering
New York State Department of Environmental Conservation

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Division of Occupational and Radiological Health
Environmental Health Services
Oklahoma State Department of Health

Environmental Radiation Surveillance Program
Division of Sanitation and Engineering
Oregon State Board of Health

Radiological Health Section
Bureau of Environmental Health
Pennsylvania Department of Public Health

Radiological Health Services
Division of Preventable Diseases
Tennessee Department of Public Health

Division of Occupational Health
Environmental Health Services
Texas State Department of Health

Radiation Control Section
Division of Health
Washington State Department of Social and Health Services

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Food and Diet Surveillance

Efforts are being made by various Federal and State agencies to estimate the dietary intake of selected radionuclides on a continuing basis. These estimates, along with the guidance developed by the Federal Radiation Council, provide a basis for evaluating the significance of radioactivity in foods and diet.

Networks presently in operation and reported include those listed below. These networks provide data useful for developing estimates of nationwide dietary intakes of radionuclides. Programs reported in *Radiological Health Data and Reports* are as follows:

Program	Period reported	Issue
California Diet Study	January–June 1970	November 1970
Carbon-14 and Tritium in Total Diet and Milk	January 1969–June 1970	January 1971
Connecticut Standard Diet	July–December 1969	December 1970
Institutional Diet Samples	July–September 1970	February 1971
Strontium-90 in Tri-City Diets	January–December 1969	June 1970

SECTION II. WATER

The Environmental Protection Agency and other Federal, State, and local agencies operate extensive water quality sampling and analysis programs for surface, ground, and treated water. Most of these programs include determinations of gross beta and gross alpha radioactivity and specific radionuclides.

Although the determination of the total radionuclide intake from all sources is of primary importance, a measure of the public health importance of radioactivity levels in water can be obtained by comparison of the observed values with the Public Health Service Drinking Water Standards (*1*). These standards, based on consideration of Federal Radiation Council (FRC) recommendations (2–4), set the limits for approval of a drinking water supply containing radium-226 and strontium-90 at 3 pCi/liter and 10 pCi/liter, respectively. Limits may be set higher if the total intake of radioactivity from all sources remains within the guides recommended by FRC for control action. In the known absence[1] of strontium-90 and alpha-particle emitters, the limit is 1,000 pCi/liter gross beta radioactivity, except when additional analysis indicates that concentrations of radionuclides are not likely to cause exposures greater than the limits indicated by the Radiation Protection Guides. Surveillance data from a number of Federal and State programs are published periodically to show current and long-range trends. Water sampling activities reported in *Radiological Health Data and Reports* are listed below.

[1] Absence is taken to mean a negligibly small fraction of the specific limits of 3 pCi/liter and 10 pCi/liter for unidentified alpha-particle emitters and strontium-90, respectively.

Water sampling program	Period reported	Issue
California	July–December 1968	August 1970
Interstate Carrier Drinking Water	1967–1969	December 1970
Kansas	January–December 1969	September 1970
Minnesota	January–June 1969	January 1970
North Carolina	January–December 1967	May 1969
New York	January–June 1969	June 1970
Radiostrontium in Tap Water, HASL	January–June 1970	April 1971
Tritium in Community Water Supplies	1969	December 1970
Tritium in Surface Waters	January–June 1970	November 1970
Washington	July 1968–June 1969	February 1971

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Radiostrontium in Tap Water, January-June 1970

Health and Safety Laboratory
U.S. Atomic Energy Commission

The Health and Safety Laboratory has performed analyses for strontium-90 in tap water at New York City since August 1954. Samples of tap water are collected daily so that by the end of the month a composite of at least 100 liters is available for analysis. Cesium-137 determinations were begun in January 1964. The analytical methods used at the laboratory are given in the Health and Safety Laboratory Manual of Standard Procedures (*1*).

Strontium-90 concentration and cesium-137 to strontium-90 ratios in New York City tap water for January through June 1970 are presented in table 1. These results appear graphically in figure 1.

A decreasing trend has been observed in the strontium-90 concentrations since the July 1963 peak. The maximum strontium-90 concentrations observed are below the acceptable limit as set forth in the interstate carrier drinking water standards (*2*).

[1] Prepared from information appearing in Fallout Program Quarterly Summary Report, HASL 239. This report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151.

Table 1. Radiostrontium in New York City tap water January–June 1970

Sampling months (1970)	Strontium-90[a] (pCi/liter)	Cesium-137/strontium-90
January	0.84	0.05
February	.65	.06
March	.64	.07
April	.67	NA
May	.59	.10
June	.65	.13

[a] Approximately 100 liters per sample.
NA, no analysis.

REFERENCES

(*1*) U.S. ATOMIC ENERGY COMMISSION. Manual of standard procedures, 40:E-38-01-16. Health and Safety Laboratory, U.S. Atomic Energy Commission, 376 Hudson Street, New York, N.Y. 10014.

(*2*) FEDERAL REGISTER RULES AND REGULATIONS. Title 42-Public Health, Chapter 1, Public Health Service, Department of Health, Education and Welfare; Part 72, Interstate Quarantine, Subpart J, Drinking Water Standards 27:2154–2155. Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (March 6, 1962).

Recent coverage in *Radiological Health Data and Reports*:

Period	Issue
January–December 1969	July 1970

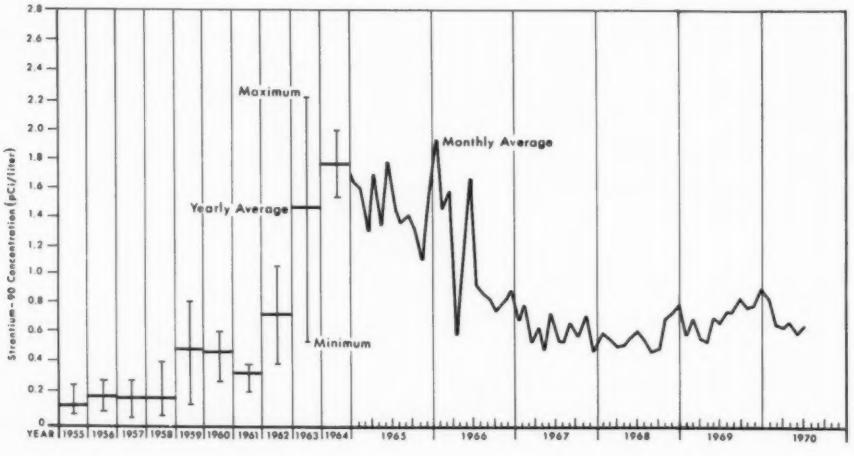

Figure 1. Strontium-90 concentrations in New York City tap water, 1955-June 1970

SECTION III. AIR AND DEPOSITION

Radioactivity in Airborne Particulates and Precipitation

Continuous surveillance of radioactivity in air and precipitation provides one of the earliest indications of changes in environmental fission product radioactivity. To date, this surveillance has been confined chiefly to gross beta radioanalysis. Although such data are insufficient to assess total human radiation exposure from fallout, they can be used to determine when to modify monitoring in other phases of the environment.

Surveillance data from a number of programs are published monthly and summarized periodically to show current and long-range trends of atmospheric radioactivity in the Western Hemisphere. These include data from activities of the Environmental Protection Agency, the Canadian Department of National Health and Welfare, the Mexican Commission of Nuclear Energy, and the Pan American Health Organization.

In addition to those programs presented in this issue, the following programs were previously covered in *Radiological Health Data and Reports:*

Network	Period	Issue
Fallout in the United States and Other Areas, *HASL*	July–December 1968 and January–December 1969	January 1971
Plutonium in Airborne Particulates and Precipitation	January–June 1970	March 1971
Surface Air Sampling Program, 80th Meridian Network, *HASL*	January–December 1967	January 1971

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1. Radiation Alert Network December 1970

Air Pollution Control Office
Environmental Protection Agency

Surveillance of atmospheric radioactivity the United States is conducted by the Radiation Alert Network (RAN) which regularly gathers samples at 70 locations distributed throughout the country (figure 1). Most of the stations are operated by State Health Department personnel.

The station operators perform "field estimates" on the airborne particulate samples at 5 hours after collection, when most of the radon daughter products have decayed, and at 29 hours after collection, when most of the thoron daughter products have decayed. They also perform field estimates on dried precipitation samples and report all results to appropriate Environmental Protection Agency officials by mail or telephone depending on levels found. A compilation of the daily field estimates is available upon request from the Data Acquisition and Analysis Branch, Division of Air Quality and Emission Data, EPA, Cincinnati, Ohio. A detailed description of the sampling and analytical procedures was presented in the March 1968 issue of *Radiological Health Data and Reports.*

Table 1 presents the monthly average gross beta radioactivity in surface air particulates and deposition by precipitation, as measured by the field estimate technique, during December 1970. Time profiles of gross beta radioactivity in air for eight Radiation Alert Network stations are shown in figure 2.

All field estimates reported were within normal limits for the reporting station with the exception of Salt Lake City, Utah, which reported 187 pCi/m³ on December 20, 1970, and 42 pCi/m³ on December 21, 1970, and Boise, Idaho, which reported 27 pCi/m³ on December 21, 1970 and 14 pCi/m³ on December 22, 1970.

These levels were due to an unplanned venting of an underground test at the Nevada Test site near Las Vegas, Nev., on December 18, 1970.

Figure 1. Radiation Alert Network sampling stations

Table 1. Gross beta radioactivity in surface air and precipitation, December 1970

Station location		Number of samples	Air surveillance gross beta radioactivity (5-hour field estimate) (pCi/m³)			Last profile in RHD&R	Number of samples	Precipitation			
								Total depth (mm)	Field estimation of deposition		
		Air	Maximum	Minimum	Average[a]				Number of samples	Depth (mm)	Total deposition (nCi/m²)
Ala:	Montgomery	22	5	0	1	Oct 70	4	116	4	116	25
Alaska:	Anchorage	0				Feb 71	0				
	Attu Island	31	0	0	0	Nov 70	0				
	Fairbanks	12	0	0	0	Mar 71	2	4	2	4	1
	Juneau	4	[b]23	1	7	Apr 71	4	105	4	105	0
	Kodiak	0				Sept 70	0				
	Nome	0				Dec 70	0				
	Point Barrow	0				Nov 70	0				
Ariz:	Phoenix	12	10	2	5	Aug 70	0				
Ark:	Little Rock	17	3	0	1	Mar 71	0				
Calif:	Berkeley	21	2	0	0	Sept 70	11	156	11	156	1
	Los Angeles	22	4	0	1	Dec 70	0				
C.Z:	Ancon	0				Sept 70	0				
Colo:	Denver	24	7	1	3	Sept 70	0				
Conn:	Hartford	22	1	0	0	Apr 71	7	60	7	60	0
Del:	Dover	20	3	0	1	Feb 71	0				
D.C:	Washington	26	1	0	0	Dec 70	0				
Fla:	Jacksonville	21	2	0	1	Mar 71	5	54	5	54	107
	Miami	11	0	0	0	Apr 71	0				
Ga:	Atlanta	18	2	1	1	Jan 71	1	41	1	41	10
Guam:	Agana	0				Feb 71	0				
Hawaii:	Honolulu	25	0	0	0	Nov 70	7	64	[c]		
Idaho:	Boise	22	27	0	4	Nov 70	9	41	9	41	10
Ill:	Springfield	8	3	0	1	Dec 70	0				
Ind:	Indianapolis	22	2	0	1	Jan 71	0				
Iowa:	Iowa City	20	4	0	1	Sept 70	2	51	2	51	13
Kans:	Topeka	22	6	0	2	Mar 71	3	44	3	44	0
Ky:	Frankfort	0				Dec 70	0				
La:	New Orleans	20	1	0	0	Aug 70	6	81	[c]		
Maine:	Augusta	0				Jan 71	0				
Md:	Baltimore	22	2	0	1	Apr 71	4	28	4	28	0
Mass:	Lawrence	22	0	0	0	Sept 70	4	58	4	58	0
	Winchester	21	1	0	0	Oct 70	6	123	6	123	0
Mich:	Lansing	21	1	0	0	Nov 70	0				
Minn:	Minneapolis	21	2	0	0	Feb 71	3	30	3	30	6
Miss:	Jackson	17	1	0	0	Aug 70	3	53	2	28	0
Mo:	Jefferson City	22	4	0	1	Jan 71	4	47	4	47	0
Mont:	Helena	19	8	0	1	Oct 70	3	12	3	12	0
Nebr:	Lincoln	10	12	1	4	Jan 71	0				
Nev:	Las Vegas	15	4	1	1	Apr 71	0				
N.H:	Concord	0				Dec 70	0				
N.J:	Trenton	20	1	0	0	Aug 70	6	71	6	71	2
N.Mex:	Santa Fe	20	2	0	1	Oct 70	0				
N.Y:	Albany	0				Jan 71	2	22	2	22	12
	Buffalo	19	1	0	0	Sept 70	0				
	New York City	0				Oct 70	0				
N.C:	Gastonia	16	15	1	6	Sept 70	4	42	[c]		
N Dak:	Bismarck	22	1	0	0	Dec 70	3	12	3	12	2
Ohio:	Cincinnati	0				Feb 71	0				
	Columbus	0				Aug 70	0				
	Painesville	17	3	0	1	Apr 71	6	71	6	71	0
Okla:	Oklahoma City	16	7	1	2	Nov 70	0				
	Ponca City	21	11	1	3	Apr 71	2	30	2	30	0
Oreg:	Portland	21	2	0	0	Jan 71	15	219	15	219	18
Pa:	Harrisburg	13	1	0	0	Feb 71	1	10	1	10	1
P.R:	San Juan	0				Aug 70	0				
R.I:	Providence	17	1	0	0	Nov 70	0				
S.C:	Columbia	18	6	0	2	Oct 70	5	96	5	96	6
S. Dak:	Pierre	22	4	0	1	Aug 70	0				
Tenn:	Nashville	19	2	0	1	Nov 70	8	92	8	92	2
Tex:	Austin	0				Feb 71	0				
	El Paso	1	1	1	1	Dec 70	0				
Utah:	Salt Lake City	30	187	0	8	Jan 71	6	48	6	48	4
Vt:	Barre	19	1	0	0	Mar 71	9	96	9	96	13
Va:	Richmond	22	1	0	0	Mar 71	3	55	3	55	54
Wash:	Seattle	12	1	0	0	Mar 71	7	89	[c]		
	Spokane	15	3	0	1	Feb 71	0				
W. Va:	Charleston	22	2	0	1	Oct 70	9	75	9	75	11
Wisc:	Madison	22	2	0	0	Mar 71	7	17	6	16	2
Wyo:	Cheyenne	22	4	1	1	Apr 71	2	6	2	6	0
Network summary		1,038	187	0	1		183	69	5	60	9

[a] The monthly average is calculated by weighting the field estimates of individual air samples with length of sampling period.
[b] These data are suspect.
[c] This station is part of the plutonium in precipitation network. No gross beta measurements are done.

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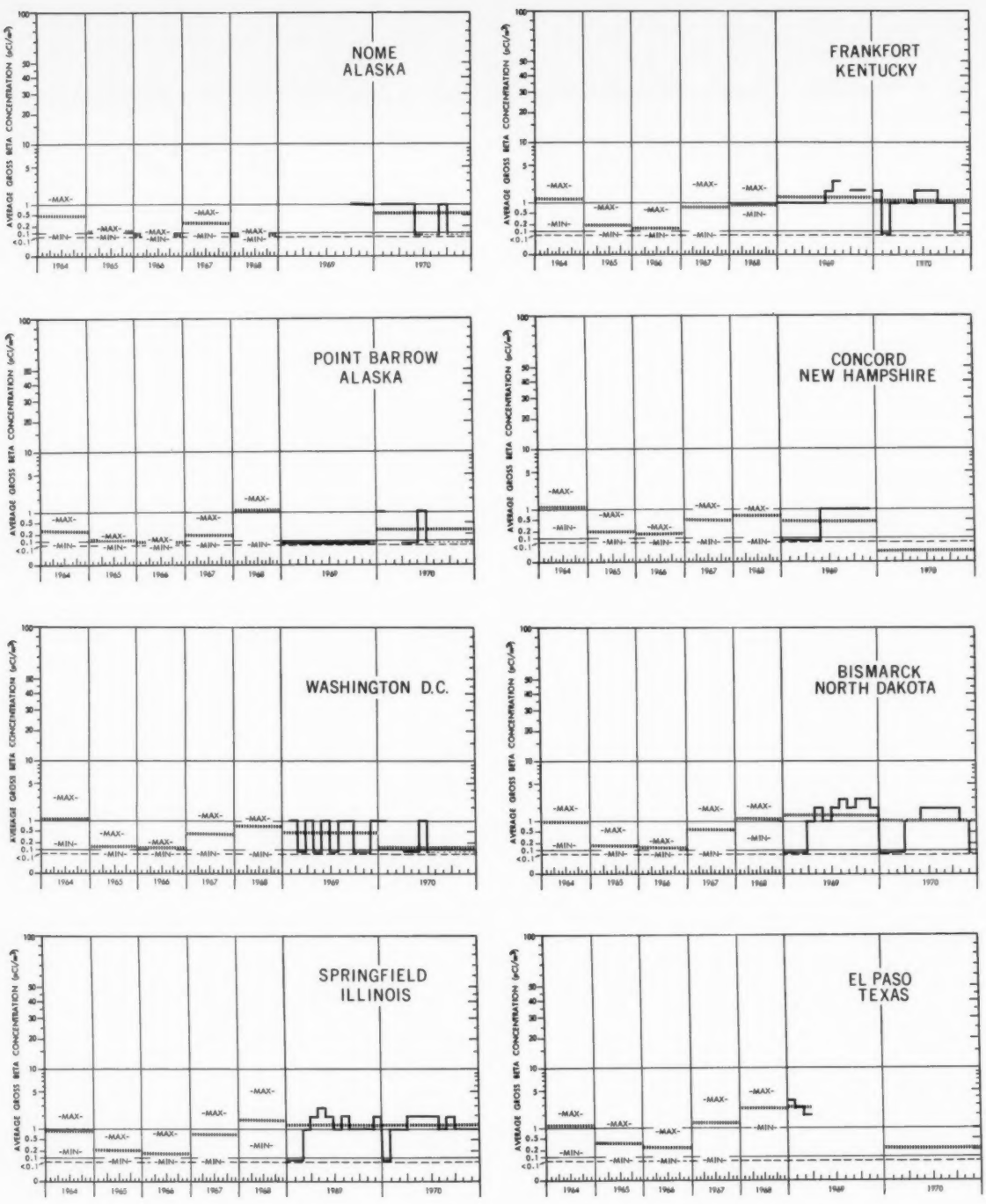

Figure 2. Monthly and yearly profiles of beta radioactivity in air—Radiation Alert Network, 1964–December 1970

2. Canadian Air and Precipitation Monitoring Program[1], December 1970

Radiation Protection Division
Department of National Health and Welfare

The Radiation Protection Division of the Canadian Department of National Health and Welfare monitors surface air and precipitation in connection with its Radioactive Fallout Study Program. Twenty-four collection stations are located at airports (figure 3), where the sampling equipment is operated by personnel from the Meteorological Services Branch of the Department of Transport. Detailed discussions of the sampling procedures, methods of analysis, and interpretation of results of the radioactive fallout program are contained in reports of the Department of National Health and Welfare (*1–5*).

A summary of the sampling procedures and methods of analysis was presented in the May 1969 issue of *Radiological Health Data and Reports.*

Surface air and precipitation data for December 1970 are presented in table 2.

[1] Prepared from information and data obtained from the Canadian Department of National Health and Welfare, Ottawa, Canada.

Table 2. Canadian gross beta radioactivity in surface air and precipitation, December 1970

Station	Number of samples	Air surveillance gross beta radioactivity (pCi/m³)			Precipitation measurements	
		Maximum	Minimum	Average	Average concentration (pCi/liter)	Total deposition (nCi/m²)
Calgary	4	0.1	0.0	0.1	31	0.30
Coral Harbour	4	.1	.0	.1	47	.23
Edmonton	4	.1	.1	.1	166	.34
Ft. Churchill	4	.1	.1	.1	24	.24
Fredericton	2	.1	.0	.1	8	1.24
Goose Bay	4	.1	.0	.1	5	.37
Halifax	4	.1	.1	.1	7	1.43
Inuvik	3	.1	.0	.1	23	.41
Montreal	4	.1	.0	.0	5	.50
Moosonee	4	.1	.1	.1	48	1.77
Ottawa	2	.2	.0	.1	14	1.11
Quebec	4	.1	.1	.1	8	.35
Regina	10	.3	.1	.1	17	.31
Resolute	1	.1	.1	.1	203	.20
St. John's, Nfld	2	.0	.0	.0	NS	NS
Saskatoon	10	.2	.1	.1	1	.03
Sault Ste. Marie	10	.2	.1	.1	18	1.02
Thunder Bay	10	.2	.0	.1	12	.75
Toronto	10	.7	.0	.2	21	1.70
Vancouver	4	.0	.0	.0	2	.37
Whitehorse	4	.1	.0	.1	14	.25
Windsor	10	.6	.0	.3	4	.18
Winnipeg	10	.2	.1	.1	17	.41
Yellowknife	3	.1	.1	.1	22	.39
Network summary	127	0.7	0.0	0.1	31	0.60

NS, no sample.

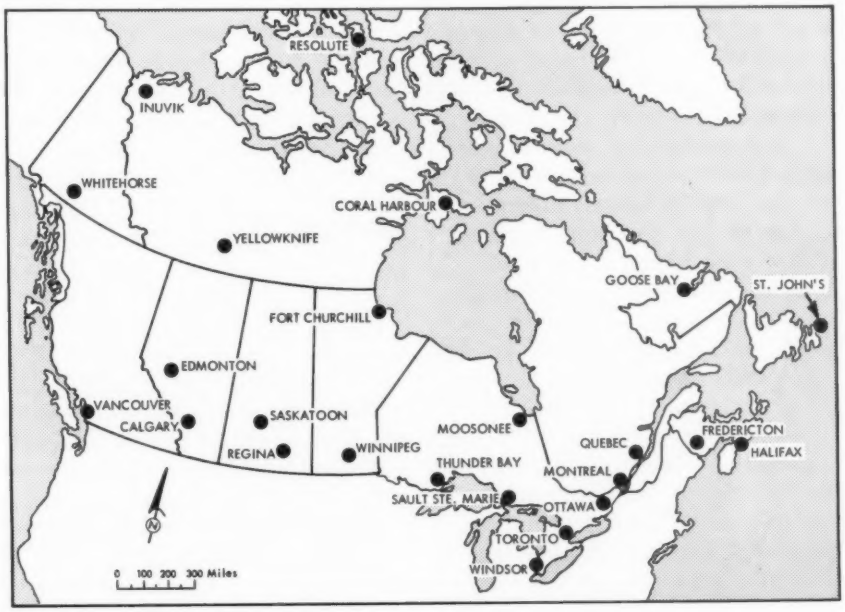

Figure 3. Canadian air and precipitation sampling stations

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3. Pan American Air Sampling Program December 1970

Pan American Health Organization and *Environmental Protection Agency*

Gross beta radioactivity in air is monitored by countries in the Americas under the auspices of the collaborative program developed by the Pan American Health Organization (PAHO) and the Environmental Protection Agency (EPA) to assist PAHO-member countries in developing radiological health programs.

The air sampling station locations are shown in figure 4. Analytical techniques were described in the March 1968 issue of *Radiological Health Data and Reports*. The December 1970 air monitoring results from the participating countries are given in table 3.

Table 3. Summary of gross beta radioactivity in Pan American surface air, December 1970

Station location	Number of samples	Gross beta radioactivity (pCi/m³)		
		Maximum	Minimum	Average[a]
Argentina: Buenos Aires	NS			
Bolivia: La Paz	12	0.31	0.00	0.10
Chile: Santiago	19	.38	.05	.18
Colombia: Bogota	21	.06	.00	.03
Ecuador: Cuenca	NS			
Guayaquil	NS			
Quito	NS			
Guyana: Georgetown	9	.06	.01	.03
Jamaica: Kingston	NS			
Peru: Lima	25	.40	.03	.25
Venezuela: Caracas	6	.07	.01	.03
West Indies: Trinidad	11	.13	.00	.06
Pan American summary	103	0.40	0.00	0.12

[a] The monthly average is calculated by weighting the individual samples with length of sampling period. Values less than 0.005 pCi/m³ are reported and used in averaging as 0.00 pCi/m³.
NS, no sample.

Figure 4. Pan American Air Sampling Program Stations

REFERENCES

(1) BIRD, P. M., A. H. BOOTH, and P. G. MAR. Annual report for 1959 on the Radioactive Fallout Study Program, CNHW-RP-3. Department of National Health and Welfare, Ottawa, Canada (May 1960).

(2) BIRD, P. M., A. H. BOOTH, and P. G. MAR. Annual report for 1960 on the Radioactive Fallout Study Program, CNHW-RP-4. Department of National Health and Welfare, Ottawa, Canada (December 1961).

(3) MAR, P. G. Annual report for 1961 on the Radioactive Fallout Study Program, CNHW-RP-5. Department of National Health and Welfare, Ottawa, Canada (December 1962).

(4) BEALE, J. and J. GORDON. The operation of the Radiation Protection Division Air Monitoring Program, RPD-11. Department of National Health and Welfare, Ottawa, Canada (July 1962).

(5) BOOTH, A. H. The calculation of permissible levels of fallout in air and water and their use in assessing the significance of 1961 levels in Canada, RPD-21. Department of National Health and Welfare, Ottawa, Canada (August 1962).

Surface Air Sampling Program-80th Meridian Network January-December 1968

Health and Safety Laboratory
Atomic Energy Commission

The Health and Safety Laboratory began its Surface Air Sampling Program in January 1963, as a continuation of the 80th Meridian Program conducted by the U.S. Naval Research Laboratory. The objectives of this program are to determine the concentrations of radioactivity in surface air in both hemispheres as a function of latitude and season and to interpret these data in terms of the dominant meteorological and physical processes which are operative.

The basic network consists of a line of sites approximately along the 80th Meridian extending from about 76° N to 90° S latitudes (figure 1). Since 1963, a number of sites have been added to investigate the possible effects of longitude, elevation, and proximity to coastlines; and in late 1965, samplers were placed on four Atlantic Ocean weather ships to extend the surface air study over the marine environment. The Environmental Science Services Administration, Department of Commerce, maintains a collection site at the Amundson Scott Station in Antarctica. The air filter samples from this site are also included in the HASL program.

Sampling and analytical procedures

Approximately 1,400 cubic meters of ambient air per day are drawn through an 8-inch diameter microsorban filter for the land stations. For the ocean stations, about 2,200 cubic meters of air per day are filtered by an 8- by 10-inch microsorban filter. Each filter is changed on the 1st, 8th, 15th, and 22nd of the month or more frequently if the filter becomes clogged with debris suspended in the air. Under normal conditions, the filters from each station are compressed into a monthly composite, and the gamma spectrum of the composite is obtained by analysis with an 8- by 4-inch NaI (Tl) crystal approximately 2 weeks after the last collection in the month.

The integrated response between 100 keV and and 3.0 MeV is corrected by the average detection efficiency (35 percent) of the gamma photons present in fallout, and the total gamma radioactivity is reported in units of photons/min/1,000 m^3. Average monthly gamma concentrations are calculated by weighting the concentrations in each sampling interval by the relative period of time in the interval. After the gamma measurements have been completed, monthly composites from each site are submitted to contractor laboratories for radiochemical analyses.

Since the last major nuclear weapon test series occurred at the end of 1962, only the longer lived, artifically produced radionuclides were present in the filters analyzed prior to May 1966. Consequently, emphasis was given to the determination of manganese-54, iron-55, strontium-90, cadmium-109, cesium-137, cerium-144, plutonium-238, and plutonium-239. Strontium-89, zirconium-95 and cerium-141 were analyzed in samples collected after the foreign nuclear test of May 1966.

The longer lived fission products and plutonium-239 concentrations should describe the general distribution in surface air of all previous nuclear weapon debris which was transferred from the lower stratosphere to the troposphere during the collection period of this report. Other tracer radionuclides can be associated with debris from a single detonation or a series of detonations.

[1] Summarized from "Fallout Program Quarterly Summary Report," HASL 224,239 available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151.

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Figure 1. 80th Meridian Network sampling stations

Manganese-54 and iron-55 were produced in large quantities in the 1961 and 1962 test series. Cadmium-109 was generated by the U.S. high altitude test over Johnston Island on July 9, 1962. While plutonium-238 is present in low concentrations in nuclear weapons debris, about 17,000 curies of plutonium-238 was disseminated at high altitude in the stratosphere on April 21, 1964 during the reentry burnup of a SNAP-9A power source. As the levels of any of the radionuclides drop to below practical determination limits, they are eliminated from the radiochemical program; thus cadmium-109 was not analyzed after the end of 1967.

During 1968, Tracerlab, Incorporated, of Richmond, Calif. (now known as Trapelo Division/West) performed the analyses of most of the samples in this program.

Table 1. Station location

Site		Latitude	Longitude (west)	Elevation (meters)
Greenland:	Thule	76° 36′ N	68° 35′	259
Ocean station:	Bravo	56° 30′ N	51° 00′	0
	Charlie	52° 45′ N	35° 30′	0
Ontario:	Moosonee	51° 16′ N	80° 30′	10
Wash:	Seattle	47° 36′ N	122° 22′	3
Ocean station:	Delta	44° 00′ N	41° 00′	0
N.J:	Westwood	41° 00′ N	74° 01′	38
N.Y:	New York City	40° 48′ N	73° 58′	38
Va:	Sterling	38° 58′ N	77° 25′	76
Ocean station:	Echo	35° 00′ N	48° 00′	0
Fla:	Miami	25° 49′ N	80° 17′	4
Bahamas:	Bimini	25° 46′ N	79° 22′	3
Hawaii:	Mauna Loa	19° 28′ N	155° 36′	3,401
P.R:	San Juan	18° 26′ N	66° 00′	10
Panama:	Balboa	8° 58′ N	79° 34′	23
Ecuador:	Guayaquil	2° 10′ S	79° 52′	7
Peru:	Lima	12° 01′ S	77° 08′	13
Bolivia:	Chacaltaya	16° 21′ S	68° 07′	5,220
Chile:	Antofagasta	23° 37′ S	70° 16′	31
	Isle de Pasqua-Easter Isle	27° 10′ S	109° 26′	41
	Portillo	32° 50′ S	70° 08′	2,850
	Santiago	33° 27′ S	70° 42′	520
	Puerto Montt	41° 27′ S	72° 57′	7
	Punta Arenas	53° 08′ S	70° 53′	35

Results

The radioactivity concentrations in surface air during January–December 1968 are presented in tables 2 through 9. The sites are listed according to latitude beginning with the most northern site at Thule, Greenland (table 1). The results of the blank and standard analyses are reported in tables 10 and 11.

The concentrations are reported at the midpoint of the collection month for the plutonium isotopes and the fission products and on October 15, 1961 for the induced radionuclide, iron-55.

Table 2. Iron-55 concentrations in surface air, January–December 1968[a]

Site		Concentration[b] (dpm/1,000 standard m³ at midmonth)					
		Jan	Feb	Mar	Apr	May	June
Greenland:	Thule	31.63	33.17	39.27	27.93	32.00	—
Ocean station:	Bravo	13.95	[c]7.32	28.66	34.14	16.82	12.12
	Charlie	19.25	45.15	34.78	16.83	30.04	30.63
Ontario:	Moosonee	15.70	26.42	43.95	37.66	69.18	77.00
Ocean station:	Delta	20.30	—	32.08	54.83	47.60	38.69
N.Y:	New York City	39.10	36.11	50.28	52.62	87.38	86.81
Va:	Sterling	38.03	[c]32.10	69.60	104.24	65.03	79.84
Ocean station:	Echo	20.27	—	25.24	61.88	52.03	51.05
Fla:	Miami	52.49	60.77	105.57	78.82	51.53	29.82
Bahamas:	Bimini	77.20	68.45	120.66	187.07	56.38	—
Hawaii:	Mauna Loa	36.20	18.42	61.06	109.03	66.07	78.72
P.R:	San Juan	20.67	[c]22.66	59.89	71.07	40.32	55.46
Panama:	Balboa	[c]14.96	19.03	41.81	87.30	[c]6.99	[c]13.10
Ecuador:	Guayaquil	[d]	[d]	[b]4.70	[d]	[d]	[c]10.21
Peru:	Lima	[c]19.50	[d]	[c]16.55	[d]	[d]	[c]26.52
Bolivia:	Chacaltaya	[d]	[d]	[c]5.33	[d]	[c]5.47	[c]11.25
Chile:	Antofagasta	[c]16.96	[d]	[d]	[d]	[d]	[c]16.11
	Isle de Pasqua-Easter Isle	—	[c]29.85	—	[d]	—	—
	Santiago	[c]46.94	[d]	[c]59.73	[d]	[c]40.86	—
	Puerto Montt	[d]	[c]6.57	[b]6.90	[d]	[d]	[c]7.60
	Punta Arenas	[d]	[d]	[d]	[c]10.71	[d]	—

[a] No data reported for July–December 1968.
[b] Errors are less than 20 percent except:
[c] error between 20–100 percent.
[d] error greater than 100 percent.
—, no data reported.

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One standard deviation of the counting error for these data is always less than ±20 percent unless otherwise indicated.

Table 3. Strontium-89 concentrations in surface air January–December 1968[a]

Site		Concentration[b] (dpm/1,000 standard m³ at midmonth)		
		Jan	July	Aug
Greenland:	Thule	17.30	4.76	[c]1.17
Ocean station:	Bravo	7.97	[c].66	5.13
	Charlie	24.69	4.35	—
Ontario:	Moosonee	12.59	[c]8.47	[c]2.96
Ocean station:	Delta	—	—	[c]1.00
N.Y:	New York City	26.42	—	2.07
Va:	Sterling	—	6.96	4.22
Ocean station:	Echo	36.97	—	[c]3.83
Fla:	Miami	88.31	—	9.60
Bahamas:	Bimini	124.87	—	9.93
Hawaii:	Mauna Loa	253.12	—	13.24
P.R:	San Juan	70.47	—	18.87
Panama:	Balboa	51.78	—	71.47
Ecuador:	Guayaquil	2.42	11.65	277.51
Peru:	Lima	[c].80	—	899.06
Bolivia:	Chacaltaya	[c].35	—	2,153.61
Chile:	Antofagasta	[c]1.16	—	625.30
	Portillo	[c]—	525.49	2,504.03
	Santiago	[c]1.73	—	408.10
	Puerto Montt	[c]1.31	2.33	103.02
	Punta Arenas	[c].47	[d]	20.29

[a] No data reported from February through June and September through December 1968.
[b] Errors are less than 20 percent except:
[c] Error between 20–100 percent
[d] Error greater than 100 percent
—, no data reported.

Three quality control samples are submitted along with each monthly shipment of samples for analysis. A weighed aliquot of a standard solution of a nuclide to be analyzed is added to two of these filters, and the third filter serves as a blank. The pattern of additions is varied for each nuclide so that different filters are blanks for different nuclides.

All the values reported by the contractor are corrected for a reagent blank, so that the blank values reported here reflect the contamination of the filter material both during manufacture and during handling at HASL and at the contractor laboratory.

Table 10 lists the results of the analyses of the blanks for each nuclide. In general, these data indicate low levels of contamination for most of the nuclides, however, it is significant to note that the average plutonium-238 blank rose from 0.04 dpm in 1967 to 0.22 dpm in 1968. Because the amount of plutonium-238 found in surface air samples is frequently in the range of 1 dpm, this blank may represent a significant fraction of the total radioactivity.

The results of analyses on standard samples are shown in table 11. These data are indicative

Table 4. Strontium-90 concentrations in surface air, January–December 1968

Site		Concentration[a] (dpm/1,000 standard m³ at midmonth)											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Greenland:	Thule	2.61	4.04	6.07	4.53	4.33	3.92	3.13	5.30	4.11	1.80	2.22	—
Ocean station:	Bravo	1.00	1.22	3.50	4.14	3.08	2.85	1.90	1.80	1.68	1.59	1.13	1.12
	Charlie	1.74	2.64	3.26	3.19	4.06	3.39	2.38	—	2.35	1.10	1.52	.57
Ontario:	Moosonee	1.77	2.91	6.23	7.84	9.01	9.32	6.00	5.56	4.83	—	1.07	1.82
Ocean station:	Delta	2.25	—	4.79	7.00	5.56	5.14	4.52	4.81	2.61	2.13	—	1.80
N.Y:	New York City	3.16	4.53	7.53	9.95	11.00	6.87	8.23	6.22	6.08	2.92	1.94	2.49
Va:	Sterling	—	4.99	7.54	10.85	9.15	10.11	9.12	5.29	5.26	3.78	2.43	2.70
Ocean station:	Echo	2.28	—	3.83	7.66	7.29	6.27	5.92	4.95	2.13	3.78	2.06	2.55
Fla:	Miami	3.46	5.90	13.17	14.85	4.72	3.06	4.19	3.90	2.39	2.97	3.62	3.23
Bahamas:	Bimni	4.77	7.18	9.12	11.95	5.66	2.84	3.81	5.12	1.53	8.33	—	—
Hawaii:	Mauna Loa	5.16	2.77	7.45	13.68	10.39	11.66	6.20	5.36	4.07	2.16	1.33	2.61
P.R:	San Juan	2.64	3.42	9.31	14.39	5.78	4.96	5.86	4.23	2.93	3.16	1.17	2.15
Panama:	Balboa	2.22	2.16	5.89	9.87	1.08	.37	2.02	1.83	.63	.32	[b].52	1.09
Ecuador:	Guayaquil	.68	.72	.53	.43	.42	.39	.35	2.58	2.30	1.04	.66	3.27
Peru:	Lima	1.61	1.53	1.17	.83	.51	.59	1.14	8.85	6.83	4.15	6.67	4.26
Bolivia:	Chacaltaya	.35	[b] .16	[b] .83	.51	.53	0.81	[b]7.62	19.28	12.73	3.97	4.49	4.43
Chile:	Antofagasta	2.00	1.40	1.52	.73	.93	1.32	2.27	6.47	5.56	3.56	4.71	3.17
	Isle de Pasqua-Easler Isle	1.73	1.70	—	1.26	—	—	—	—	—	—	—	—
	Portillo	—	—	—	—	—	—	6.51	24.84	2.37	—	—	—
	Santiago	2.81	2.09	2.07	.89	.96	1.00	1.29	5.48	4.66	2.05	5.52	3.43
	Puerto Montt	1.81	1.25	1.12	.82	[b].52	.53	.54	1.72	1.74	1.22	1.74	2.20
	Punta Arenas	.83	.90	.95	.82	.42	.33	[b].52	.53	.75	.56	.68	.80

[a] Errors are less than 20 percent except:
[b] Error between 20–100 percent.
[c] Error greater than 100 percent.
—, no data reported.

Table 5. Zirconium-95 concentrations in surface air, January–December 1968

Site		Concentration[a] (dpm/1,000 standard m³ at midmonth)											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Greenland:	Thule	76.01	60.34	50.64	31.46	19.78	13.51	12.18	9.77	5.20	2.30	2.50	—
Ocean station:	Bravo	23.25	16.04	29.61	25.30	16.51	10.12	4.48	3.30	—	1.92	1.59	.95
	Charlie	46.89	37.73	34.06	22.73	20.32	11.03	6.18	—	3.28	1.83	1.72	.81
Ontario:	Moosonee	25.72	33.83	57.17	47.53	41.65	30.99	17.97	10.59	9.07	—	—	1.77
Ocean station:	Delta	89.35	—	39.62	47.14	28.75	17.16	13.95	8.65	4.54	3.19	—	—
N.Y:	New York City	85.11	70.15	77.53	66.49	51.16	34.36	25.03	13.35	37.42	—	—	2.70
Va:	Sterling	78.72	68.17	72.36	63.13	44.04	33.95	23.12	13.24	13.51	6.43	—	3.59
Ocean station:	Echo	54.68	—	—	50.09	32.74	22.85	15.03	10.45	—	—	4.56	3.46
Fla:	Miami	112.44	95.64	131.96	103.22	33.93	—	10.74	26.05	24.31	16.11	—	—
Bahamas:	Bimini	146.37	118.87	143.53	114.78	34.95	[b] .68	16.57	30.58	26.80	34.75	—	—
Hawaii:	Mauna Loa	155.49	31.27	58.26	83.28	39.64	32.84	16.20	28.31	50.17	31.18	—	10.43
P.R:	San Juan	48.70	37.82	90.93	84.04	27.96	—	18.45	29.28	33.54	—	—	5.74
Panama:	Balboa	48.49	34.05	54.16	65.08	5.01	[b] 1.52	7.62	77.45	—	13.25	—	6.08
Ecuador:	Guayaquil	3.93	3.21	[b] 3.74	[b] 2.78	1.13	[b] .49	21.67	476.08	205.16	—	—	145.70
Peru:	Lima	4.02	1.91	24.50	[b]	[b] .76	[b] .67	60.68	1,025.82	596.98	355.72	—	178.46
Bolivia:	Chacaltaya	[b] .57	[b] .49	[b]	[b] .91	[b] .78	[b] 1.36	1,396.15	3,343.37	1,534.69	—	267.69	181.57
Chile:	Antofagasta	5.94	[b] 1.84	[b] 1.98	[c]	[b] .62	[b] .57	175.47	895.38	434.24	256.79	—	156.34
	Isle de Pasqua-Easter Isle	—	[b] 1.04	—	[b] .55	—	—	—	—	—	—	—	—
	Portillo	—	—	—	—	—	—	619.61	3,096.78	55.93	—	—	—
	Santiago	6.60	[b] 2.03	[b] 1.00	[b]	[b] .54	—	137.64	579.44	317.56	—	151.40	119.33
	Puerto Montt	4.37	1.45	.52	.39	[b]	[b]	6.12	125.52	98.48	—	91.38	—
	Punta Arenas	2.04	[b] .85	[b] .53	[b] .37	[b]	[b]	[b]	27.40	—	—	23.86	23.34

[a] Errors are less than 20 percent except:
[b] error between 20–100 percent
[c] error greater than 100 percent
—, no data reported.

of the accuracy of the radiochemical analyses. The values shown are the average percent deviations between the added activities and the results reported by the contractor. Although most of the results are satisfactory, there appears to be a large positive bias in the plutonium-238 values for much of 1968, which cannot be accounted for by the increase of the blank contamination.

Table 6. Cesium-137 and cerium-141 concentrations in surface air during 1968[a]

Site		Concentration[b] (dpm/1,000 standard m³ at midmonth)						
		Cesium-137						Cerium-141[a]
		July	Aug.	Sept	Oct.	Nov	Dec	Jan
Greenland:	Thule	7.66	8.32	6.44	3.23	4.36	—	67.73
Ocean station:	Bravo	2.86	2.93	2.51	2.40	1.72	1.52	40.81
	Charlie	3.68	—	4.25	1.55	2.29	.87	53.57
Ontario:	Moosonee	11.39	10.12	8.37	—	2.58	2.71	[c] 13.44
Ocean station:	Delta	6.89	6.94	3.67	1.94	—	2.89	—
N.Y:	New York City	18.30	12.48	10.42	6.74	4.36	4.80	53.90
Va:	Sterling	12.62	9.17	8.66	4.88	4.67	4.39	[c] 88.30
Ocean station:	Echo	9.84	7.83	3.11	6.19	3.38	4.12	55.88
Fla:	Miami	8.24	8.01	3.40	3.02	6.94	8.27	261.19
Bahamas:	Bimini	9.49	10.92	3.05	18.00	—	—	295.34
Hawaii:	Mauna Loa	10.30	8.96	6.26	3.38	1.84	3.90	314.54
P.R:	San Juan	9.05	8.49	4.65	5.28	1.95	3.47	[c] 71.76
Panama:	Balboa	3.80	2.71	.89	[c] .09	.71	1.64	[c] 100.82
Ecuador:	Guayaquil	.67	4.95	3.39	2.57	3.84	5.60	[c] 8.21
Peru:	Lima	2.00	11.92	8.26	3.71	8.90	6.30	[d]
Bolivia:	Chacaltaya	10.46	28.04	17.43	6.78	6.09	6.08	[c][d] 13.64
Chile:	Antofagasta	3.60	10.66	7.93	[d]	7.11	6.32	[d]
	Portillo	9.41	36.94	3.09	—	—	—	—
	Santiago	2.93	9.10	7.37	4.85	7.83	6.17	[c] 21.73
	Puerto Montt	.82	2.24	2.28	1.63	2.46	3.09	[c] 6.83
	Punta Arenas	.58	.71	1.21	.80	.87	1.09	[d]

[a] Cesium-137, no data reported for January–June 1968
Cerium-141 no data reported for February–December 1968.
[b] Errors are less than 20 percent except:
[c] error between 20–100 percent.
[d] error greater than 100 percent.
—, no data reported.

XUM

Table 7. Cerium-144 concentrations in surface air, January–December 1968

Site		Concentration[a] (dpm/1,000 standard m³ at midmonth)											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Greenland:	Thule	39.28	60.58	82.19	76.06	66.89	62.19	65.31	46.36	45.05	23.65	25.51	—
Ocean station:	Bravo	12.93	16.34	51.34	69.68	52.65	45.03	26.13	25.32	21.32	18.08	11.93	8.90
	Charlie	30.28	38.94	56.81	66.19	74.56	47.87	32.96	—	27.59	14.37	14.42	6.21
Ontario:	Moosonee	17.33	36.30	100.22	123.38	157.65	159.32	105.74	74.23	61.50	—	15.93	15.49
Ocean station:	Delta	38.27	—	76.20	122.26	102.88	77.39	65.69	62.11	30.89	24.96	—	18.57
N.Y:	New York City	47.31	72.79	127.28	185.50	194.68	181.29	152.45	81.11	65.30	40.91	27.05	24.36
Va:	Sterling	46.28	75.86	124.62	185.94	159.84	153.58	128.31	78.61	69.75	38.05	27.94	26.32
Ocean station:	Echo	28.79	—	71.73	140.34	124.47	105.67	85.37	66.37	[b] 23.90	47.93	23.30	24.20
Fla:	Miami	69.40	115.90	242.13	278.82	134.18	53.98	75.19	65.26	33.50	78.55	46.08	48.37
Bahamas:	Bimini	91.71	140.00	266.39	348.28	131.12	51.77	81.33	92.88	27.42	111.48	—	—
Hawaii:	Mauna Loa	85.46	47.78	120.25	249.83	176.07	166.55	85.33	64.39	55.89	179.86	16.82	25.83
P.R:	San Juan	47.15	44.82	168.13	236.91	101.61	76.75	82.76	71.59	41.14	40.56	13.12	21.98
Panama:	Balboa	26.44	40.21	104.53	157.41	16.97	6.34	33.25	33.42	15.28	6.24	6.85	11.58
Ecuador:	Guayaquil	4.00	3.64	6.59	6.96	4.51	1.80	5.62	128.95	—	52.62	73.28	98.53
Peru:	Lima	5.48	2.95	2.55	1.73	2.78	2.49	17.82	288.73	189.42	20.82	175.67	117.91
Bolivia:	Chacaltaya	[b] .44	.71	.84	2.55	2.39	5.73	270.38	756.02	436.73	153.93	118.77	110.20
Chile:	Antofagasta	7.70	3.51	2.34	1.72	2.89	2.82	39.75	255.47	148.48	105.43	124.69	102.93
	Santiago	11.43	4.60	3.09	1.53	2.65	1.83	37.07	166.36	120.99	82.27	121.50	98.00
	Puerto Montt	6.02	2.93	1.37	1.07	.62	.64	1.81	33.18	31.31	24.53	45.17	43.54
	Punta Arenas	3.24	1.81	1.31	.82	.56	.60	—	7.28	12.28	9.73	12.03	15.64

[a] Errors are less than 20 percent except:
[b] error between 20–100 percent.
—, no data reported.

Table 8. Plutonium-238 concentrations in surface air, January–December 1968

Site		Concentration[a] (dpm/1,000 standard m³ at midmonth)											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Greenland:	Thule	3.18	3.46	3.84	2.42	1.65	2.25	1.91	1.95	1.77	1.43	1.18	—
Ocean station:	Bravo	2.26	—	[b]2.50	2.77	1.88	3.59	1.33	.95	2.91	1.02	[b]1.14	[b].43
	Charlie	1.69	2.08	2.22	2.04	2.58	2.72	2.66	—	1.48	.92	1.20	[b].56
Ontario:	Moosonee	1.93	2.86	4.62	4.60	5.69	[b]4.07	3.56	3.85	3.75	—	6.75	[b].97
Ocean station:	Delta	1.91	—	7.37	4.37	2.78	2.37	—	2.11	1.45	1.75	—	1.18
N.Y:	New York City	5.47	4.83	7.94	7.49	—	32.21	19.98	8.68	6.98	4.10	2.21	4.02
Va:	Sterling	3.91	[b]5.97	[b]6.86	6.13	5.36	[b]3.40	3.90	2.38	3.13	1.64	1.46	4.55
Ocean station:	Echo	[b]1.51	—	28.43	4.84	[b]3.10	3.65	—	3.26	2.26	2.34	1.43	1.56
Fla:	Miami	3.48	[b]3.10	10.44	7.72	4.03	1.75	2.44	2.48	.90	1.62	2.36	2.51
Bahamas:	Bimini	5.52	5.86	10.74	11.11	4.08	[b]1.35	3.12	3.63	.73	6.33	—	—
Hawaii:	Mauna Loa	[b]3.12	—	4.30	7.09	5.29	5.41	2.65	2.52	3.35	1.65	[b].48	1.62
P.R:	San Juan	2.77	3.17	[b]4.40	6.78	5.75	2.78	3.13	[b]2.03	2.47	[b]2.97	[c]	1.16
Panama:	Balboa	2.37	2.06	3.05	6.06	[b].85	[b].35	1.23	.82	[b].41	[b].21	[c]	.76
Ecuador:	Guayaquil	4.72	4.20	[b]1.69	[b]1.50	2.63	5.55	1.91	[b]1.56	[b]2.45	3.05	2.49	3.29
Peru:	Lima	6.70	7.10	[b]4.55	4.66	2.33	2.75	3.91	4.06	[b]4.84	5.20	6.83	6.33
Bolivia:	Chacaltaya	3.68	[b].53	2.15	3.01	2.08	2.77	3.03	4.94	8.61	3.18	3.66	3.70
Chile	Antofagasta	10.67	[b]7.04	7.39	4.18	3.88	4.31	5.40	5.91	5.58	5.33	6.43	6.68
	Isle de Pasqua-Easter Island	6.67	[b].58	—	5.38	—	—	—	—	—	—	—	—
	Portillo	—	—	—	—	—	—	13.37	23.55	[b]2.45	—	—	—
	Santiago	17.62	11.26	10.58	—	5.52	4.52	5.09	9.28	8.89	6.16	[b]6.88	6.13
	Puerto Montt	8.02	6.22	4.41	3.68	1.72	2.47	1.98	2.95	3.36	[b]2.32	3.11	3.40
	Punta Arenas	3.55	3.65	4.50	3.87	1.42	1.33	[b]1.83	1.46	1.78	1.42	1.33	[b]1.96

[a] Errors are less than 20 percent except:
[b] error between 20–100 percent
[c] error greater than 100 percent
—, no data reported.

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Recent coverage in *Radiological Health Data and Reports*:

Period	Issue
January–December 1967	January 1971

Table 9. Plutonium-239 concentrations in surface air, January–December 1968

Site		Concentration[a] (dpm/1,000 standard m³ at midmonth)											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Greenland:	Thule	—	10.05	11.87	9.79	9.40	15.06	10.17	13.39	10.05	5.77	6.17	—
Ocean station:	Bravo	—	—	7.64	9.68	7.59	114.32	4.60	4.55	4.56	4.30	2.77	2.76
	Charlie	—	4.76	7.61	8.39	20.14	13.14	4.57	—	6.16	3.15	4.33	1.75
Ontario:	Moosonee	—	7.56	14.48	16.34	23.36	28.81	17.39	14.14	12.53	—	4.16	4.67
Ocean station:	Delta	4.68	—	13.02	17.02	13.74	14.06	11.13	11.61	8.24	6.11	—	4.97
N.Y:	New York City	—	9.58	18.99	27.28	31.43	27.24	30.18	20.13	16.43	10.08	7.70	8.02
Va:	Sterling	—	8.78	21.88	24.51	21.84	22.04	25.40	14.49	15.31	9.31	7.44	6.59
Ocean station:	Echo	—	—	11.23	17.95	17.67	17.50	16.22	28.36	77.07	18.22	5.83	7.18
Fla:	Miami	—	16.62	34.87	39.68	16.61	8.46	12.58	12.33	5.82	8.20	11.87	12.88
Bahamas:	Bimini	—	21.30	39.12	48.02	20.15	8.50	14.76	17.73	4.52	30.89	—	—
Hawaii:	Mauna Loa	—	—	16.14	31.51	24.36	26.49	14.37	12.27	10.17	5.59	3.46	5.47
P.R:	San Juan	—	6.64	23.38	31.17	14.68	11.93	13.16	13.88	6.84	[b]8.92	[b]4.21	5.28
Panama:	Balboa	—	6.03	11.26	23.31	2.18	.85	5.66	3.26	[b]1.29	.69	[b].90	2.44
Ecuador:	Guayaquil	—	[b]1.83	[b]1.69	[b].75	1.72	[b].71	1.26	1.97	[c]	[b].48	2.09	3.71
Peru:	Lima	—	3.86	[c]	2.25	1.31	1.69	2.17	4.67	[b]2.80	4.33	5.07	3.81
Bolivia:	Chacaltaya	—	[b].62	.86	1.82	1.08	2.32	7.58	10.18	10.45	4.64	3.17	3.19
Chile:	Antofagasta	—	[b]6.75	3.42	2.16	1.91	2.49	3.70	4.99	3.96	3.21	3.99	[b]3.05
	Isle de Pasqua-Easter Island	3.73	[b]1.16	—	1.77	—	—	—	—	—	—	—	—
	Portillo	—	—	—	—	—	—	7.53	16.01	[b]1.63	—	—	—
	Santiago	—	5.72	4.47	2.21	4.05	[b]1.59	2.49	5.83	3.93	3.37	8.23	4.67
	Puerto Montt	—	2.79	2.51	1.39	.79	1.21	[b].92	2.03	1.57	[c]	1.55	2.29
	Punta Arenas	—	2.23	2.49	1.36	.94	[b].69	[b].96	[b].47	.84	[b].66	.56	[b]3.10

[a] Errors are less than 20 percent except:
[b] error between 20–100 percent.
[c] error greater than 100 percent.
—, no data reported.

Table 10. Quality control results on blank samples—1968 (Values in dpm/sample ±1 standard deviation)

Month	Iron-55	Strontium-89	Strontium-90	Zirconium-95	Cesium-137	Cerium-141	Cerium-144	Plutonium-238	Plutonium-239
January	42	7.5	0	2.5	NA	13	1.5	.34	.04
February	24	NA	.5	3.0	NA	NA	2.0	NA	NA
March	62	NA	23.8	0	NA	NA	6.7	.18	.09
April	0	NA	0	1.4	NA	NA	5.4	0	0
May	0	NA	0	0	NA	NA	0	.29	.03
June	96	NA	1.6	3.1	NA	NA	0	.37	0
July	NA	7.1	.5	.9	0.2	NA	2.1	.36	.12
August	NA	0	.5	9.3	.7	NA	2.0	.29	.05
September	NA	0	0	2.8	1.5	NA	1.6	.41	0
October	NA	NA	0	NA	5.2	NA	3.0	.11	0
November	NA	NA	.1	5.7	.9	NA	.9	.06	0
December	NA	NA	.9	13.5	.1	NA	229	.11	0

NA, no analysis.

Table 11. Quality control results on standard samples, 1968 (average values in percent deviation)

Month	Iron-55	Strontium-89	Strontium-90	Zirconium-95	Cesium-137	Cerium-144	Plutonium-238	Plutonium-239
January	12.5	−12.5	−4.0	−13.0	NA	−2.0	−8.5	−3.5
February	18.0	NA	−16.0	−19.5	NA	−1.5	17.0	3.0
March	21.5	NA	−1.0	−21.0	NA	−3.0	15.5	.5
April	5.5	NA	−5.5	−13.5	NA	.5	16.0	−.5
May	−5.0	NA	−22.0	−22.0	NA	2.5	9.5	1.0
June	13.0	NA	−9.0	−16.0	NA	3.5	10.0	1.0
July	NA	NA	1.0	−6.0	11.0	10.0	10.0	1.0
August	NA	66.5	−13.5	−6.0	−5.0	−2.0	29.0	−3.5
September	NA	−11.5	−6.5	−7.0	−8.0	2.0	9.0	.5
October	NA	NA	−3.5	NA	−6.0	1.0	26.5	2.0
November	NA	NA	−1.5	−11.5	NA	8.0	39.0	6.1
December	NA	NA	−5.0	−14.8	1.0	4.5	35.0	3.9

NA, no analysis.

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SECTION IV. OTHER DATA

This section presents results from routine sampling of biological materials and other media not reported in the previous sections. Included here are such data as those obtained from human bone sampling, Alaskan surveillance, and environmental monitoring around nuclear facilities.

Strontium-90 in Human Bone, April-June 1970[1]

Radiation Office
Environmental Protection Agency

To obtain data on the concentration of strontium-90 in man by age and geographical region, the Public Health Service began collecting human bone specimens in late 1961. Analyses of selected samples of people in older-age groups have shown their bone strontium-90 content to be low and age independent (1). Consequently, the target population includes children and young adults up to 25 years of age.

Although a few samples come from living persons as a result of surgical procedures, the majority are obtained post mortem. In the latter case, the specimens are limited to accident victims or persons who have died of an acute disease process that was not likely to impair bone metabolism. For analytical purposes, a sample of at least 100 grams of wet bone is desired. Generally, this amount is readily available from older children, but it presents some difficulties from the standpoint of infants and children under 5 years of age. Most specimens received to date have been vertebrae and ribs.

[1] Period during which death or surgical procedure occurred.

Laboratory procedures

The bones are analyzed at the Northeastern Radiological Health Laboratory at Winchester, Mass. Sample collection and preparation are explained elsewhere (*2*). Strontium-90 is measured by tributyl phosphate extraction of its yttrium daughter, which is precipitated as an oxalate. The strontium-90 content is then calculated (*3*) from the yttrium-90 activity. For the purpose of maintaining analytical reproducibility, "blind"

Figure 1. Geographical regions for human bone sampling

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Table 1. Strontium-90 in human bone, April–June 1970

Bone region and State	Bone type[a]	Age[b] (years)	Sex	Strontium-90 concentration[c] (pCi/kg bone)	Calcium concentration (g/kg bone)	$^{90}Sr/Ca$ (pCi/g)
Northeast:						
Pennsylvania	V	1	M	86.0± 9.8	32.4	2.65
Massachusetts	V	3	F	57.4± 6.3	26.4	2.18
Maine	V	4	M	95.3± 8.5	25.7	3.71
Massachusetts	V	4	M	71.2± 9.4	26.7	2.67
Rhode Island	V	4	F	63.3± 8.3	29.3	2.16
Massachusetts	V	5	F	85.1±10.7	27.7	3.08
Pennsylvania	V	5	M	80.7± 9.6	33.9	2.38
New York	V	6	M	111.0± 8.6	32.3	3.44
Massachusetts	V	6	M	68.3± 8.3	32.1	2.13
	V	6	M	86.1± 9.9	34.1	2.53
New York	V	7	M	114.1±12.7	48.4	2.36
Massachusetts	V	7	F	76.7± 7.2	28.4	2.70
	V	8	M	67.5± 8.7	27.4	2.46
New York	V	8	M	41.3± 7.7	24.2	1.71
Pennsylvania	V	9	M	53.8± 7.7	39.0	1.38
	V	9	F	82.3±12.1	49.9	1.65
Massachusetts	V	9	M	45.4± 7.1	27.1	1.68
Rhode Island	S	10	M	22.2± 4.0	11.9	1.86
Massachusetts	V	11	F	104.0±11.0	28.3	3.67
Pennsylvania	V	12	M	110.4± 9.9	44.6	2.48
New York	V	12	M	81.5± 7.8	44.6	1.83
Maine	V	13	M	94.0± 9.2	39.4	2.39
Massachusetts	V	13	F	65.3± 6.6	36.6	1.79
New York	V	13	M	86.5± 7.2	41.5	2.09
Massachusetts	V	14	M	129.6±10.9	32.2	4.02
Pennsylvania	V	15	M	60.1± 6.3	41.0	1.47
	V	17	M	130.0± 9.5	53.4	2.44
	V	17	M	121.6±12.5	54.8	2.22
	V	17	M	165.1±16.9	64.9	2.54
Massachusetts	V	17	F	84.8±11.2	48.8	1.74
Pennsylvania	V	17	M	142.5±12.3	49.3	2.89
	V	17	M	107.5± 8.7	50.5	2.13
Massachusetts	V	17	F	98.0±11.6	55.0	1.78
New York	V	17	F	62.0± 7.0	36.9	1.68
Pennsylvania	V	18	M	67.5± 8.9	54.1	1.25
	V	18	M	80.5± 9.8	48.5	1.66
	V	19	F	69.4± 7.8	55.0	1.26
Massachusetts	V	19	F	73.7± 7.4	38.7	1.91
New York	V	20	M	72.9±10.1	58.8	1.24
Pennsylvania	V	20	M	84.3±11.0	45.9	1.84
New Jersey	V	20	M	99.7±11.5	61.1	1.63
Massachusetts	V	21	M	60.5± 9.3	42.7	1.42
Pennsylvania	V	21	M	78.1±12.4	60.1	1.30
	V	22	M	73.2± 7.6	54.6	1.34
Massachusetts	V	23	M	123.6±13.7	54.8	2.26
	V	23	M	96.4± 8.5	50.8	1.90
Pennsylvania	V	25	F	110.2±12.5	56.9	1.94
Massachusetts	V	25	M	49.7± 8.2	46.1	1.08
	V	25	M	73.1± 7.7	40.8	1.79
Southeast:						
South Carolina	V	1	M	64.1±10.3	30.0	2.13
	V	5	F	82.0± 9.7	31.4	2.61
	V	6	M	58.5± 6.9	34.3	1.70
	V	6	M	94.7±12.7	80.5	1.18
	V	8	M	52.4± 6.5	33.6	1.56
	V	10	M	67.8± 8.5	32.9	2.06
Maryland	V	11	M	127.8±14.9	38.1	3.35
North Carolina	V	13	F	49.6± 6.5	25.6	1.94
	V	15	F	118.9± 9.8	36.6	3.25
Maryland	V	17	M	115.1± 9.3	53.0	2.17
South Carolina	V	18	F	40.7± 7.9	30.3	1.34
	V	18	F	99.4± 9.1	62.1	1.60
Maryland	V	20	M	110.9±13.7	52.1	2.13
South Carolina	V	22	M	96.9±11.5	30.3	3.20
	V	23	F	61.3± 8.7	41.6	1.47
Maryland	V	23	M	82.8± 7.5	44.0	1.88
Central:						
Ohio	V	0	M	41.3± 5.9	28.6	1.44
Wisconsin	V	1	M	66.5± 9.3	25.4	2.62
Michigan	V	3	F	50.3± 7.6	25.7	1.96
Wisconsin	V	3	M	31.1± 6.0	30.0	1.04
Michigan	V	3	F	88.7± 9.5	34.7	2.55
	V	3	F	147.4±12.8	31.5	4.68
Ohio	V	3	M	93.0±10.5	29.3	3.17
	V	4	F	57.2± 7.5	32.2	1.77
	V	4	F	44.2± 5.4	27.3	1.62
Michigan	V	5	F	108.4± 9.3	39.1	2.77
Ohio	V	5	F	77.0± 7.0	27.3	2.83
Wisconsin	V	6	F	84.2± 8.3	35.1	2.40
	V	7	F	68.2± 8.0	34.8	1.96
Ohio	V	8	F	62.6± 7.6	39.9	1.57
Michigan	V	8	F	63.9± 7.8	37.5	1.70
Ohio	V	8	M	61.9± 7.3	28.9	2.14
Michigan	V	9	F	75.3± 8.1	32.0	2.35

Table 1. Strontium-90 in human bone, April–June 1970

Bone region and State	Bone type[a]	Age[b] (years)	Sex	Strontium-90 concentration[c] (pCi/kg bone)	Calcium concentration (g/kg bone)	$^{90}Sr/Ca$ (pCi/g)
Wisconsin	V	10	M	38.0± 6.4	39.1	0.97
Ohio	V	11	M	69.7±11.2	44.1	1.58
Wisconsin	V	11	F	41.9± 5.2	38.9	1.08
Ohio	V	11	F	69.7± 8.6	49.7	1.40
	V	11	M	58.9± 6.8	33.3	1.77
Michigan	V	14	M	57.5± 8.9	36.1	1.59
Ohio	V	14	M	88.2± 9.1	55.2	1.60
	V	14	M	149.4±11.8	59.9	2.49
Michigan	V	14	M	90.8±12.2	56.6	1.60
Ohio	V	14	M	74.7± 8.1	46.2	1.62
	V	15	M	145.6±14.0	57.1	2.55
	V	15	M	121.9±10.5	56.7	2.15
	V	16	M	121.7± 9.4	49.6	2.45
	V	16	F	101.6±12.9	58.0	1.75
	V	16	M	91.5±10.4	52.5	1.74
	V	16	M	85.2± 9.4	32.1	2.65
	V	16	M	81.8±11.9	43.1	1.90
	V	18	F	68.7± 8.4	43.1	1.59
Central:						
Michigan	V	18	F	69.2± 8.3	46.6	1.48
Minnesota	V	18	M	141.1± 9.5	49.9	2.83
Michigan	V	18	F	130.6±13.2	55.3	2.36
Ohio	V	19	F	143.8±13.1	71.1	2.02
	V	19	F	164.9±14.7	49.1	3.36
	V	20	M	69.2± 7.2	52.1	1.33
	V	20	M	103.0± 9.0	48.7	2.11
	V	21	M	81.0±12.4	71.7	1.13
	V	21	F	105.4± 9.9	56.4	1.87
	V	22	M	72.2±11.6	55.9	1.29
	V	23	M	82.4± 7.8	52.1	1.58
Michigan	V	23	F	77.7± 7.3	48.1	1.62
Ohio	V	24	M	58.0± 8.3	55.4	1.05
	V	24	M	131.2±12.8	61.0	2.15
Delta:						
Louisiana	V	4	M	98.9±13.7	34.2	2.89
Northwest:						
Oregon	V	3	M	87.4±11.1	66.0	1.32
	V	12	M	68.0± 7.6	37.8	1.80
	V	18	F	70.2± 6.8	23.7	2.96
Washington	V	18	M	80.5± 9.6	47.5	1.69
Oregon	V	20	M	56.7± 6.0	40.6	1.40
Washington	V	20	M	92.0±11.5	57.3	1.61
Oregon	V	23	M	60.8± 9.5	48.0	1.27
	V	24	F	63.3± 9.4	51.4	1.23
Southwest:						
Texas	V	6	M	29.1± 5.2	22.3	1.31
California	S	15	M	18.5± 3.0	14.6	1.26
Texas	V	16	M	141.6±12.5	44.6	3.18
	V	17	F	88.7±12.2	51.8	1.71
California	V	18	M	62.5± 7.7	54.4	1.15
Texas	V	22	F	86.3± 8.9	44.3	1.95
North:						
Alaska	R	16	F	618.5±47.1	132.5	4.67
	R	21	M	255.7±31.7	130.9	1.95

[a] Type of bone: V, vertebrae, S, sternum, R, rib.
[b] Age given as of last birthday prior to death.
[c] Two-sigma counting error.

duplicate analyses are performed on 10 to 20 percent of the samples.

The analytical results for strontium-90 in individual bones from persons dying during the second quarter (April–June) of 1970 are presented in table 1 in order of increasing age within each geographical region. These regions are indicated in figure 1. Reported values are given in picocuries of strontium-90 per kilogram of bone (as a rough indication of dose) and per gram of calcium (for comparison with other data and for purposes of model development). Two-sigma counting errors are reported for the bone concentration.

Following the pattern of earlier reports, subsequent articles will continue to provide interpretation of the data at appropriate stages in the program (*2–6*).

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Recent coverage in *Radiological Health Data and Reports*:

Period	Issue
April–June 1969	May 1970
July–September 1969	June 1970
October–December 1969	September 1970
January–March 1970	January 1971

Environmental Levels of Radioactivity at Atomic Energy Commission Installations

The U.S. Atomic Energy Commission (AEC) receives from its contractors semiannual reports on the environmental levels of radioactivity in the vicinity of major Commission installations. The reports include data from routine monitoring programs where operations are of such a nature that plant environmental surveys are required.

Releases of radioactive materials from AEC installations are governed by radiation standards set forth by AEC's Division of Operational Safety in directives published in the "AEC Manual."[1]

Summaries of the environmental radioactivity data follow for the National Reactor Testing Station and the Portsmouth Area Gaseous Diffusion Plant.

[1] Title 10, Code of Federal Regulations, Part 20, "Standards for Protection Against Radiation" contains essentially the standards published in Chapter 0524 of the AEC Manual.

1. National Reactor Testing Station[2] July–December 1969 and Annual Summary 1969

Health Services Laboratory
U.S. Atomic Energy Commission
Idaho Falls, Idaho

Data from the environmental monitoring network on and around the National Reactor Testing Station (NRTS) in eastern Idaho revealed that NRTS operations during the second half of 1969 did not contribute significantly to environmental radiation or radioactivity concentration levels. These levels remained well below the Atomic Energy Commission (AEC) standards as set forth in AEC Manual Chapter 0524. These standards are based on Federal Radiation Council recommendations. The concentrations of radioactivity reported include contributions from all sources, such as fallout and natural radioactivity. Samples of air, water, and milk are collected routinely at stations shown in figure 1. The results of the analyses performed on the air, water, and milk samples are shown in table 1 for July–December 1969 and table 2 for the year 1969.

[2] Summarized from "Environmental Monitoring Report No. 25, July–December and Annual Summary 1969, U.S. Atomic Energy Commission, Idaho Operations Office, Health Services Laboratory.

Water monitoring

Water containing small quantities of radioactivity is returned to the ground through ponds and wells at the NRTS. The radioactivity in the water is measured before discharge to make sure that standards are not exceeded in the environment. Radioactivity is also monitored in the

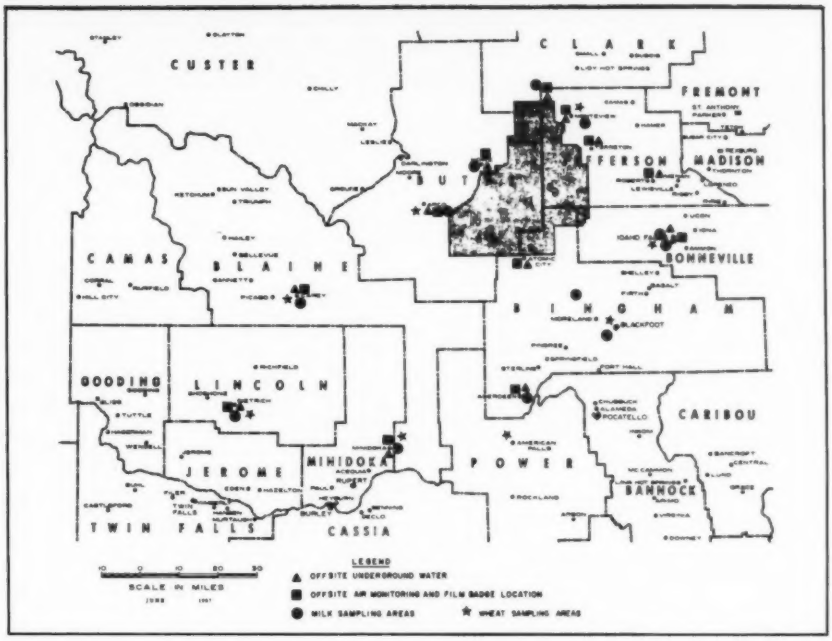

Figure 1. Environmental monitoring stations, National Reactor Testing Stations

ground water from onsite and offsite sampling locations. Samples are analyzed for gross alpha and gross beta radioactivity and tritium. Offsite surface water samples are also collected from the Snake River at Idaho Falls and Bliss, Idaho. Because offsite background concentrations were not detectable, no radioactivity representing background was subtracted from the levels measured onsite. The average concentrations of all types of radioactivity in onsite and offsite water were less than 11 percent of all respective AEC guides. The standard for onsite drinking water was changed in February 1969 from the 40-hour-per-week restricted area standard to the same standards that apply to offsite water. Radioactivity above the detection level was measured in only 4 offsite water samples during 1969.

Air monitoring

Radioactive materials in the atmosphere are collected by drawing air through filters. The samplers operate continuously, and the filters are changed weekly. The filters are analyzed for gross alpha, gross beta, and iodine-131 radioactivity. Samplers are located at eight locations onsite as shown in figure 1. The offsite gross beta and iodine-131 concentrations reported were determined from samples at Idaho Falls, Blackfoot, and Arco. The onsite gross beta and iodine-131 average levels in air were not significantly different from offsite background levels in air during 1969. The gross alpha sampling results from Arco were used as the background to which the onsite alpha air activities were compared. The Arco station was used because it has the lowest concentrations of natural alpha radioactivity. The Idaho Department of Health is conducting investigations with the help of the Health Services Laboratory to determine the cause of the airborne radioactivity concentrations at Blackfoot and Idaho Falls, which are slightly higher than at Arco or the NRTS. There was no significant difference between the NRTS and Arco's gross alpha radioactivity. All air monitoring results are listed in tables 1 and 2.

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Table 1. Environmental monitoring data for the National Reactor Testing Station, July–December 1969

Type of sample and units	Number of samples	Type of radioactivity	Minimum level of detection	Maximum radioactivity of single sample	Average radioactivity per sample	AEC standard
Onsite production well water (pCi/liter)	260	Alpha	3	3 6	<3	30
		Beta	5	113	<7	100
		Tritium	[a]2	[a]75	[a]7.7	[a]3,000
Offsite underground water (pCi/liter)	12	Alpha	3	<3	<3	30
		Beta	5	<5	<5	100
		Tritium	[a]2	[a] <2	[a] <2	[a]3,000
Surface water (pCi/liter)	2	Alpha	3	<3	<3	30
		Beta	5	<5	<5	100
		Tritium	[a]2	[a] <2	[a] <2	[a]3,000
Onsite air (pCi/m³)	208	Alpha	.001	.007	.003	0.6
		Beta	.003	2.95	.53	300
		Iodine-131	.01	.12	<.01	9,000
Offsite air (pCi/m³)	104	Alpha	.001	.005	.003	0.02
		Beta	.003	1.26	.41	10
		Iodine-131	.01	.065	<.01	100
Offsite milk (pCi/liter)	85	Iodine-131	20	<20	<20	[b]100
		Strontium-90	1	12	<3.9	[b]200
Offsite wheat (pCi/kg)	8	Strontium-90	2	13	<7.5	None
External radiation, thermoluminescent dosimeters: (mrem/6 months less natural background)						
Offsite perimeter locations	35	Gamma	5	15	6	85
On and offsite public highways:						
Highway 20	35	Gamma	5	<5	<5	85
Highway 28	19	Gamma	5	<5	<5	85
Highway 22	8	Gamma	7	<7	<7	85
Highway 28	4	Gamma	7	<7	<7	85

[a] Concentration of tritium in nCi/liter.
[b] The continuous intake guide recommended by the Federal Radiation Council.

Table 2. Environmental monitoring data for the National Reactor Testing Station, January–December 1969

Type of sample and units	Number of samples	Type of radioactivity	Minimum level of detection	Maximum racioactivity of single sample	Average radioactivity per sample	AEC standard
Onsite production well water (pCi/liter)	504	Alpha	3	6	<3	30
		Beta	5	113	<6.6	100
		Tritium	[a]2	[a]85	[a]8.3	[a]3,000
Offsite underground water (pCi/liter)	24	Alpha	3	4	<3	30
		Beta	5	5	<5	100
		Tritium	[a]2	[a] <2	[a] <2	[a]3,000
Surface water (pCi/liter)	4	Alpha	3	<3	<3	30
		Beta	5	<5	<5	100
		Tritium	[a]2	[a] <2	[a] <2	[a]3,000
Onsite air (pCi/m³)	416	Alpha	.001	.023	.003	.6
		Beta	.003	2.95	.50	300
		Iodine-131	.01	.12	<.014	9,000
Offsite air (pCi/m³)	208	Alpha	.001	.011	.003	.02
		Beta	.003	1.6	.43	10
		Iodine-131	.01	.14	.016	100
Offsite milk (pCi/liter)	176	Iodine-131	20	<20	20	[b]100
		Strontium-90	1	12	<3.2	[b]200
Offsite wheat (pCi/kg)	8	Strontium-90	2	13	<7.5	None
External radiation, thermoluminescent dosimeters: (mrem/6 months less natural background)						
Offsite perimeter locations	41	Gamma	10	[c]15	<11	170
On and offsite public highways:						
Highway 20	73	Gamma	10	[c]18	<10	170
Highway 28	38	Gamma	10	[c]7	<10	170
Highway 22	16	Gamma	12	[c] <7	<12	170
Highway 28	8	Gamma	12	[c] <7	<12	170

[a] Concentration of tritium in nCi/liter.
[b] The continuous intake guide recommended by the Federal Radiation Council.
[c] mrem/6 months.

Offsite milk monitoring

Offsite milk samples are collected from 12 locations routinely and analyzed for strontium-90 and iodine-131. A composite grade A sample is collected weekly from an Idaho Falls dairy. This composite sample contains milk from areas north, south, and east of NRTS. Milk samples are collected monthly from all sampling locations. The sampling locations are shown in figure 1, and the results are given in tables 1 and 2. No iodine-131 was detected at any time during the year. The strontium-90 concentrations in milk, including background, were less than 4 percent of the standard during 1969 and are attributed to worldwide fallout.

Wheat monitoring

Wheat samples (grain only) were collected during harvest from eight different locations. The wheat hull contains about 90 percent of the strontium-90 radioactivity. This means that only 10 percent of the radioactivity will remain after processing the wheat for use in food products. No guide has been established for the radioactivity content of field samples of wheat. The concentration of strontium-90 in wheat is attributed to worldwide fallout. The sampling locations are shown in figure 1 and the analysis results in tables 1 and 2.

Gamma radiation levels

The external gamma radiation is measured with thermoluminescent dosimeters (TLD). The exposure results reported in tables 1 and 2 represent net values after subtracting natural background exposures. An average background was determined from dosimeters placed at the offsite locations of Aberdeen, Carey, Deitrich, Idaho Falls, and Minidoka. The offsite perimeter locations are Arco, Atomic City, Butte City, Howe, Monteview, Mud Lake, and Roberts. No significant radiation exposures were observed during 1959. The maximum exposure was less than 8 percent of the AEC radiation protection standards.

Recent coverage in *Radiological Health Data and Reports*:

Period	Issue
July–December 1968	June 1970
January–June 1969	January 1971

2. Portsmouth Area Gaseous Diffusion Plant[3] January–June 1970

Goodyear Atomic Corporation
Piketon, Ohio

The separation of uranium isotopes by the gaseous diffusion process presents control problems similar to any chemical process using toxic solvents and extraction solutions. Natural uranium and thorium-234 are the most likely radionuclides to be released to the environment by the Portsmouth Area Gaseous Diffusion Plant. To verify the effectiveness of plant controls, environmental monitoring is conducted for evidence of alpha-particle, beta-particle, and gamma-ray emitters.

Previously, environmental radiation reports have reflected air sample results for both alpha and beta-gamma radioactivity taken at 21 offsite locations. These samples were taken once per month at each location. In April 1970, the Atomic Energy Commission requested that Goodyear Atomic Corporation report only the results of air samples taken from a minimum of four offsite sampling locations. Sampling at these locations should be at a frequency of at least three, 1,000 cubic foot samples per week. In selecting sample locations, the prevailing wind direction and the locations with the highest concentrations should be considered as indicated in previous reports. The air sample results in this report reflect this request.

Water samples are collected monthly at each location. The one-half gallon sample is analyzed for gross alpha and gross beta-gamma radioactivity. Moderate volumes of low-level water wastes are discharged to the Scioto River System by way of Little Beaver Creek, Big Beaver Creek and Salt Creek. Sampling point distribution is as follows: one on each of the three plant drainage

[3] Data summarized from B. Kalman and S. H. Hulett, "Environmental Radiation Levels and Concentrations, First Half 1970." (September 14, 1970)

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ditches; one on Salt Creek; three each on the Little Beaver Creek, the Big Beaver Creek, and the Scioto River. The frequency of composite sampling of water is determined by the flow at each of the three plant drainage ditches. The composite sample is collected in a 55-gallon drum. After thoroughly mixing the water in the drum, a one-half gallon sample is drawn off each month and the drum drained. The average concentrations in the Scioto River have been substantially below the AEC Radiation Protection Standards for population groups in uncontrolled areas without need for control of releases.

For January–June 1970, the alpha and beta-gamma radioactivity in water, and the alpha radioactivity in air decreased when compared with the 1969 calendar year values.

Penetrating background dose rates for the first half of 1970 remained essentially the same when compared with the calendar year 1969 values. External gamma radiation levels are taken at each location once per month. Measurements are taken with a calibrated Geiger-Mueller tube at a distance of 1 foot above ground level. These measurements are extrapolated to a distance of 3 feet. The 3-foot value has been experimentally determined as being approximately two-thirds that at the 1-foot level. These results are tabulated in μrem/h.

Average alpha and beta-gamma radioactivity concentrations in air are summarized in table 3. Table 4 contains the average alpha and beta-gamma radioactivity concentrations in water. The external gamma-ray levels, measured at the sampling locations shown in figure 2, are summarized in table 5. The overall average concentrations and background exposure rates for January–June and July–December 1969 and January–June 1970 are presented in table 6.

Table 3. Radioactivity in air, Portsmouth Plant, January–June 1970

Location	Number of samples	Alpha radioactivity concentration (fCi/m³)			Average as a percent of AEC standards[a]	Beta-gamma radioactivity concentration (pCi/m³)			Average as a percent of AEC standards[a]
		High	Low	Average		High	Low	Average	
3	38	145	<16	32	0.81	2.7	<0.016	.85	0.09
12	36	692	<16	48	1.21	2.1	< .016	.71	.07
24	37	209	<16	32	.81	1.6	< .016	.61	.06
29	35	145	<16	32	.81	1.7	< .016	.63	.06
Average	146	692	<16	36	.91	2.7	< .016	.70	.07

[a] The AEC radiation protection standard for alpha radioactivity in air–4 pCi/m³ (insoluble uranium-235), beta-gamma radioactivity–1 nCi/m³ (insoluble thorium-234); sensitivity of analysis for both alpha and beta radioactivity is 16.1 fCi/m³.

Table 4. Radioactivity in water, Portsmouth Plant, January–June 1970

Location	Number of samples	Alpha radioactivity concentration (pCi/liter)			Average as a percent of AEC standards[a]	Beta-gamma radioactivity concentration (pCi/liter)			Average as a percent of AEC standards[a]
		High	Low	Average		High	Low	Average	
1	6	4.5	<0.5	1.8	<0.01	72.0	<14.0	<14.0	<0.07
2	6	9.0	.9	3.3	.01	<14.0	<14.0	<14.0	< .07
3[b]	6	22	< .5	6.8	.02	18.0	<14.0	<14.0	< .07
4	6	2.7	< .5	.9	< .01	22.5	<14.0	<14.0	< .07
5	6	2.7	< .5	.9	< .01	<14.0	<14.0	<14.0	< .07
6	6	3.2	< .5	.9	< .01	22.5	<14.0	<14.0	< .07
7	6	110	18	46	.16	441	<14.0	125	.63
8	6	90	32	59	.20	112	<14.0	59.9	.30
10[b]	6	9.0	< .5	5.4	.02	58	<14.0	20.3	.10
11[b]	6	290	110	180	.60	554	<14.0	332	1.7
12	6	18	< .5	3.8	.01	31.5	<14.0	<14.0	< .07
13	6	58	< .5	12	.04	117	<14.0	30.6	.15
14	6	14	< .5	6.8	.02	22.5	<14.0	<14.0	< .07
Average	78	290	< .5	25	.08	554	<14.0	43.7	.22

[a] The AEC radiation protection standard for alpha radioactivity in water–30 nCi/liter (uranium-235), beta-gamma radioactivity–20 nCi/liter (thorium-234); sensitivity of analysis, alpha radioactivity–0.5 pCi/liter; beta radioactivity–14.0 pCi/liter.
[b] Composite sample.

Table 5. Background exposure rates, Portsmouth Plant January–June 1970

Location	Number of samples	Background rate[a] (μrem/h)			Background average rate extrapolated to 3-foot level (μrem/h)
		High	Low	Average	
2	5	13.1	10.0	11.7	7.8
3	37	27.6	9.0	12.9	8.6
4	5	12.9	10.7	11.9	7.9
6	5	12.4	10.9	11.7	7.8
9	5	12.9	9.3	11.7	7.8
12	35	13.8	9.8	12.1	8.1
13	5	12.9	10.9	11.9	7.9
15	5	12.9	10.0	11.7	7.8
16	5	12.6	10.0	11.9	7.9
17	5	13.8	10.7	12.1	8.1
18	5	12.6	9.5	11.9	7.9
19	5	12.3	10.2	12.4	8.3
20	5	14.3	10.2	12.4	8.3
21	5	12.4	10.5	11.7	7.8
22	5	11.7	10.5	10.9	7.3
23	4	13.8	10.5	11.9	7.9
24	36	16.4	10.7	13.8	9.2
25	5	13.3	10.2	11.4	7.6
26	5	13.3	9.5	11.9	7.9
27	4	14.0	11.4	12.4	8.3
28	5	13.8	10.9	12.9	8.6
29	34	16.7	12.1	14.0	9.3
Average	230	27.6	9.0	12.1	8.1

[a] Open-shield Geiger tube 1 foot above ground; limit of sensitivity—0.1 μrem/h.

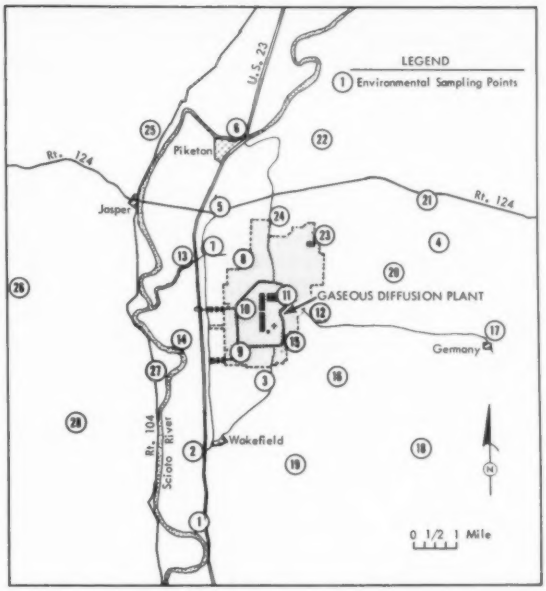

Figure 2. Sampling locations, Portsmouth Area Gaseous Diffusion Plant

Table 6. Comparison of average concentrations, Portsmouth January 1969–June 1970

Type of monitoring	Percent of AEC standard[a]			
	January–June 1969	July–December 1969	Calendar year 1969	January–June 1970
Air:				
Alpha radioactivity	<5.0	[b]10.1	5.7	0.91
Beta-gamma radioactivity	.2	.05	.03	.07
Water:				
Alpha radioactivity	.20	.22	.20	.08
Beta-gamma radioactivity	.38	.29	.32	.22
Background exposure extrapolated to 3 feet above ground level: (μrem/h)	7.9	8.5	8.2	8.1

[a] See footnote (a) of tables 2 and 3. Note units for background exposure.
[b] This value was influenced by three high values in August, however, all values were considerably below the AEC standards. There is no explanation for the high result.

Recent coverage in *Radiological Health Data and Reports*:

Period	Issue
January–June 1969	April 1970
July–December 1969	October 1970

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Reported Nuclear Detonations, March 1971

(Includes seismic signals presumably from foreign nuclear detonations)

The U.S. Atomic Energy Commission announced that on March 22, 1971, the United States recorded seismic signals, presumably from a Soviet underground nuclear explosion. The signals, which originated in the Semipalatinsk nuclear test area, were equivalent to those of an underground nuclear explosion in the low-intermediate yield range (20–200 kilotons TNT equivalent).

On March 23, 1971, the United States recorded seismic signals, presumably from a Soviet underground nuclear explosion. The signals originated from the southern Ural area and were equivalent to those of an underground nuclear explosion in the low-intermediate yield range (20–200 kilotons TNT equivalent).

There were no announced nuclear tests for the United States for March 1971.

Not all of the nuclear detonations in the United States are announced immediately, therefore, the information in this section may not be complete. A complete list of announced U. S. nuclear detonations may be obtained upon request from the Division of Public Information, U. S. Atomic Energy Commission, Washington, D. C. 20545.

SYNOPSES

Synopses of reports, incorporating a list of key words, are furnished below in reference card format for the convenience of readers who may wish to clip them for their files.

DOSE ASSESSMENT OF IONIZING RADIATION EXPOSURE TO THE POPULATION. *Michael S. Terpilak, Charles L. Weaver,* and *Samuel Wieder. Radiological Health Data and Reports, Vol. 12,* April 1971, pp. 171–188.

The population dose from natural background, residual weapons test fallout, nuclear power operations, and medical and dental uses of ionizing radiation has been reviewed. Reported and projected population exposures from these sources indicate that, for the near future, the predominant exposure to the public will be attributable to natural background and to medical x rays. A continual evaluation to assess priorities, based on magnitude and type of exposure, and investigations into the biological effects of radiation constitute important features of public health responsibility.

A declining trend is in prospect for exposure to weapons test fallout, in the absence of major atmospheric nuclear explosions. Exposure resulting from all procedures related to nuclear power operations and from diagnostic medical radiation (x rays and internally administered radionuclides) is projected to become of increasing consequence. These warrant increased attention in planning for surveillance. Surveillance associated with peaceful uses of nuclear explosions (Plowshare Program), and with tests of nuclear engines for propulsion, requires individual programming.

KEYWORDS: Dose, genetic, organ, tissue, whole body, ionizing radiation, environment, population, nuclear reactors, radionuclides, assessment, projection.

PUBLIC HEALTH ASPECTS OF IODINE-129 FROM THE NUCLEAR POWER INDUSTRY. *John L. Russell* and *Paul B. Hahn. Radiological Health Data and Reports, Vol. 12,* April 1971, pp. 189–194.

The production of iodine-129 in nuclear power reactors and its subsequent environmental releases during fuel reprocessing represents a potential long-term public health problem. Because of its extremely long half-life, any discharged iodine-129 is essentially a permanent contaminant in the biosphere, where it will eventually be found as a fraction of total iodine within a locality and possibly worldwide. This potential problem, its possible geographical scope, and the projected impact on population exposure are discussed along with data from measurements at nuclear power reactors and a fuel reprocessing plant.

A concentration of 0.86 percent iodine-129 in total iodine produces the dose limit recommended by the Federal Radiation Council (FRC) for a suitable sample of an exposed population. The quantity of iodine-129 discharged from operating power reactors was estimated from measurements of iodine-131 discharges by calculating an iodine-129 to iodine-131 buildup ratio. This analysis showed that the iodine-129 discharge from operating power reactors was negligible. Measurements at a fuel reprocessing plant indicated that approximately 10 percent of the total iodine-129 inventory in spent fuel was discharged from the stack during the batch dissolution process. The liquid discharge concentrations were about 2 percent of the total iodine-129 inventory. Iodine-129 levels in deer thyroids taken in the reprocessing plant locality were about 40 percent of levels of FRC guidance for human thyroids.

KEYWORDS: Iodine-129, fuel reprocessing plant, power reactor, environmental monitoring, dose, thyroid.

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STATISTICAL LIMITS OF ACCURACY AND PRECISION OF GROSS ALPHA AND BETA RADIOACTIVITY MEASUREMENTS IN WATER. *Edmond J. Baratta* and *Forrest E. Knowles, Jr. Radiological Health Data and Reports, Vol. 12*, April 1971, pp. 195–198.

This paper presents the results of a technical experiment designed to determine the effectiveness of measurements for gross alpha and beta radioactivity in water. Since this analysis is normally used as a "screening" technique, it is essential that the limits of precision and accuracy of the method be known. Gross measurements are still being used in preoperational reactor surveys as an indication of the "background" levels and to monitor radioactivity when the reactor becomes operational. In addition, the Public Health Service standand for drinking water has, in lieu of a determination of radium-226 and strontium-90, limits for gross alpha and beta radioactivity, respectively.

The precision and accuracy of a standard method for analysis of gross alpha and beta radioactivity in water were determined through the cooperation of private and government laboratories. It was found that gross alpha radioactivity could be determined with an overall precision of 12 percent, while the gross beta radioactivity could be determined with a precision of 7 percent. The accuracy of the gross alpha activity measurements was within 10 percent, and for the gross beta activity measurements, 1 percent.

KEYWORDS: Accuracy, detection limits, gross alpha radioactivity, gross beta radioactivity, precision, water..

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